A New Method for Determining Overlapped High-and-Low Clouds and Their Optical Properties Using MODIS Data

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Outline

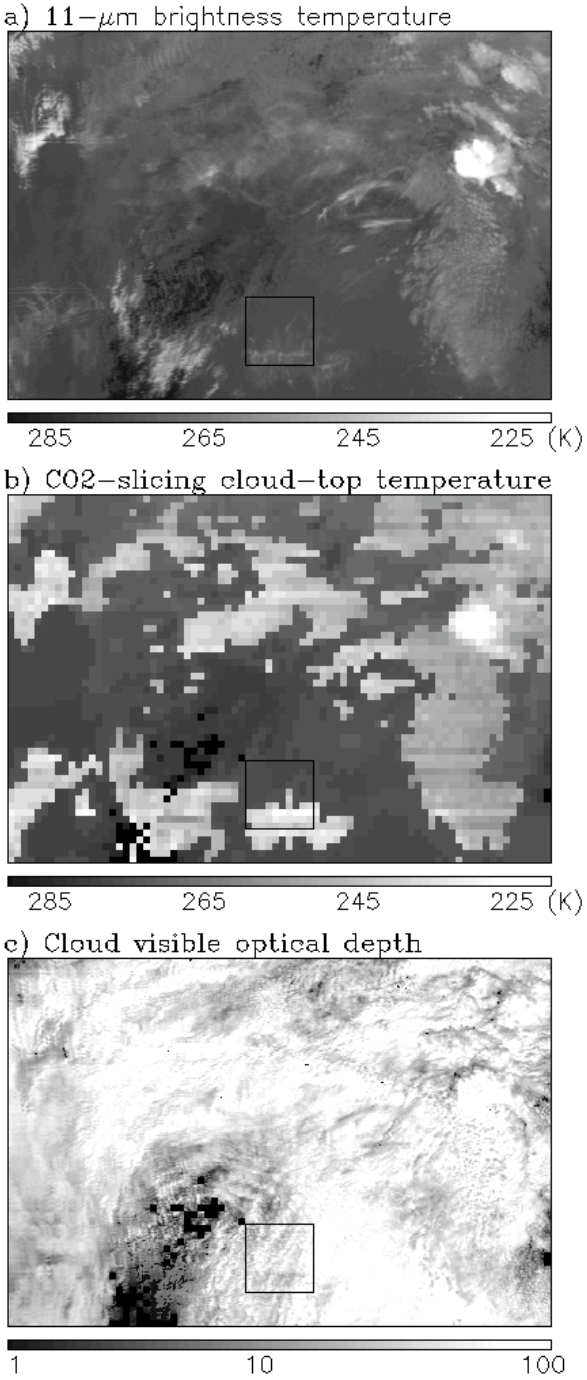
- Comparisons of three different cloud retrieval methods
  - The MODIS cloud top properties and optical depth products.
  - A conventional infrared-visible (IR-VIS) bi-spectral method like the ISCCP.
  - A new dual-layer overlapped method –

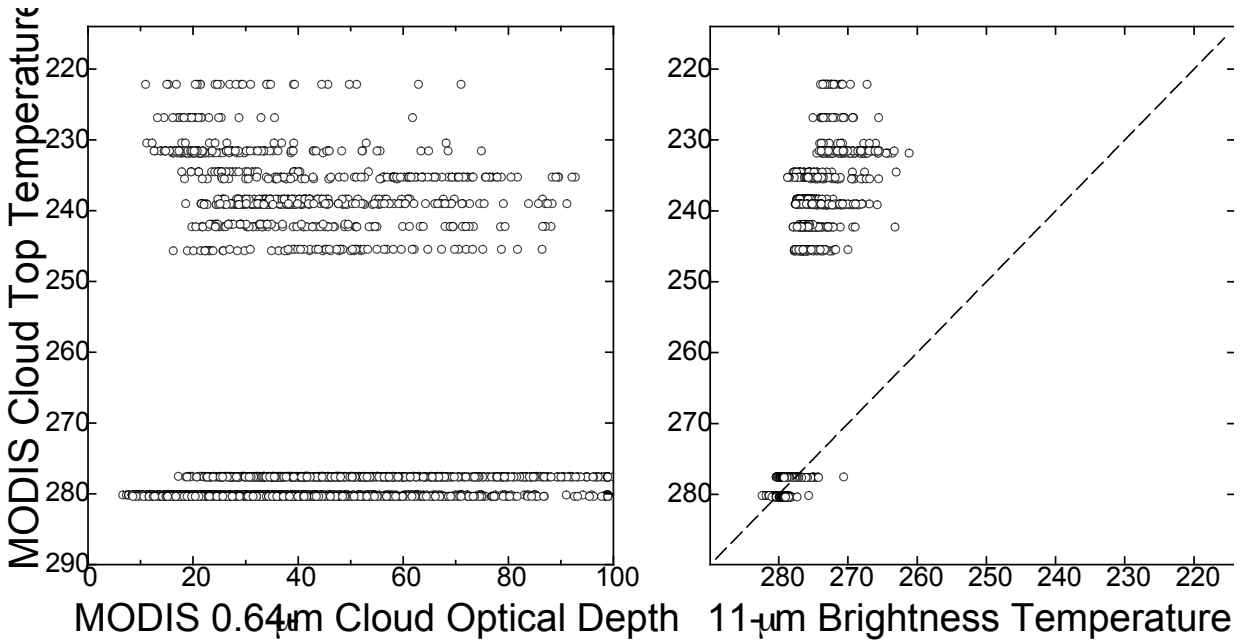
    for determining overlapped high-and-low cloud on a pixel scale, including both its high-cloud optical depth (τ_{hc}) and top altitude (P_{hc}/T_{hc}) and its low-cloud optical depth (τ_{lc}) and top altitude (P_{lc}/T_{lc}).
- Demonstration, application, and verification of the dual-layer overlapped retrieval algorithm.

Motivation for This Study

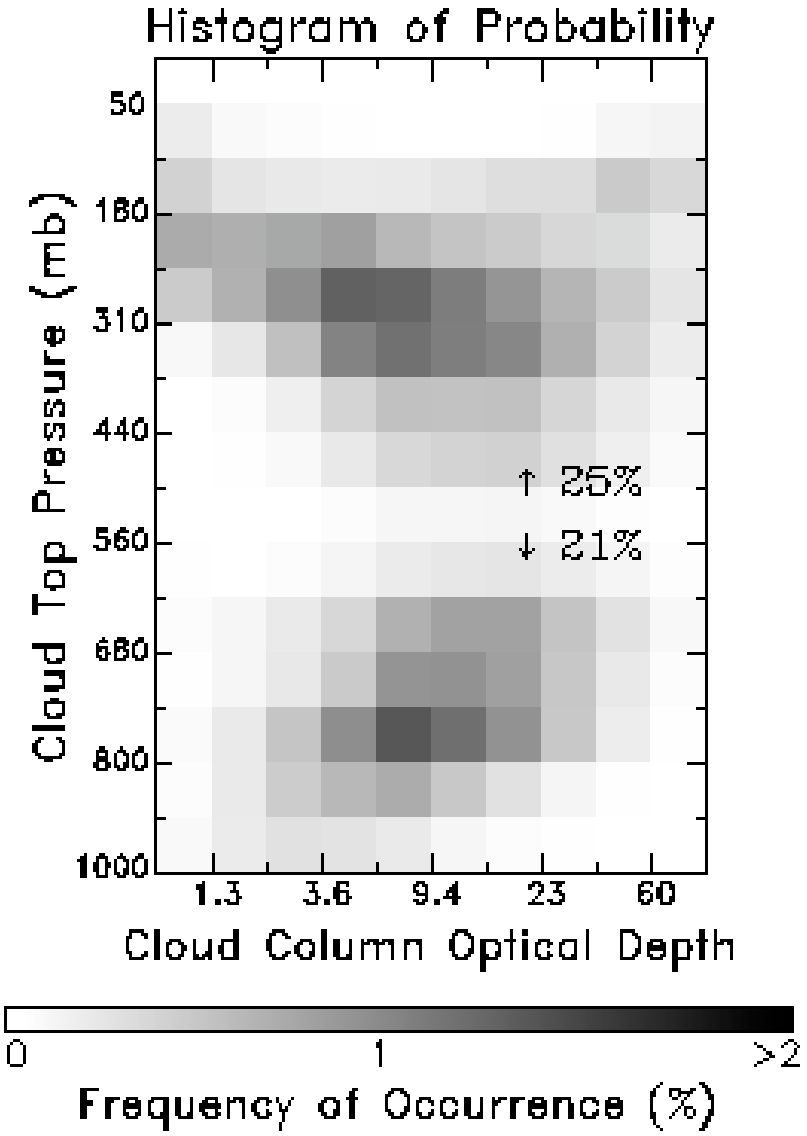
- When thin cirrus cloud overlaps thick low cloud, the conventional single-layer cloud retrieval models (IR or VIS) will not work, or will incur very large errors.

Motivation (continued)



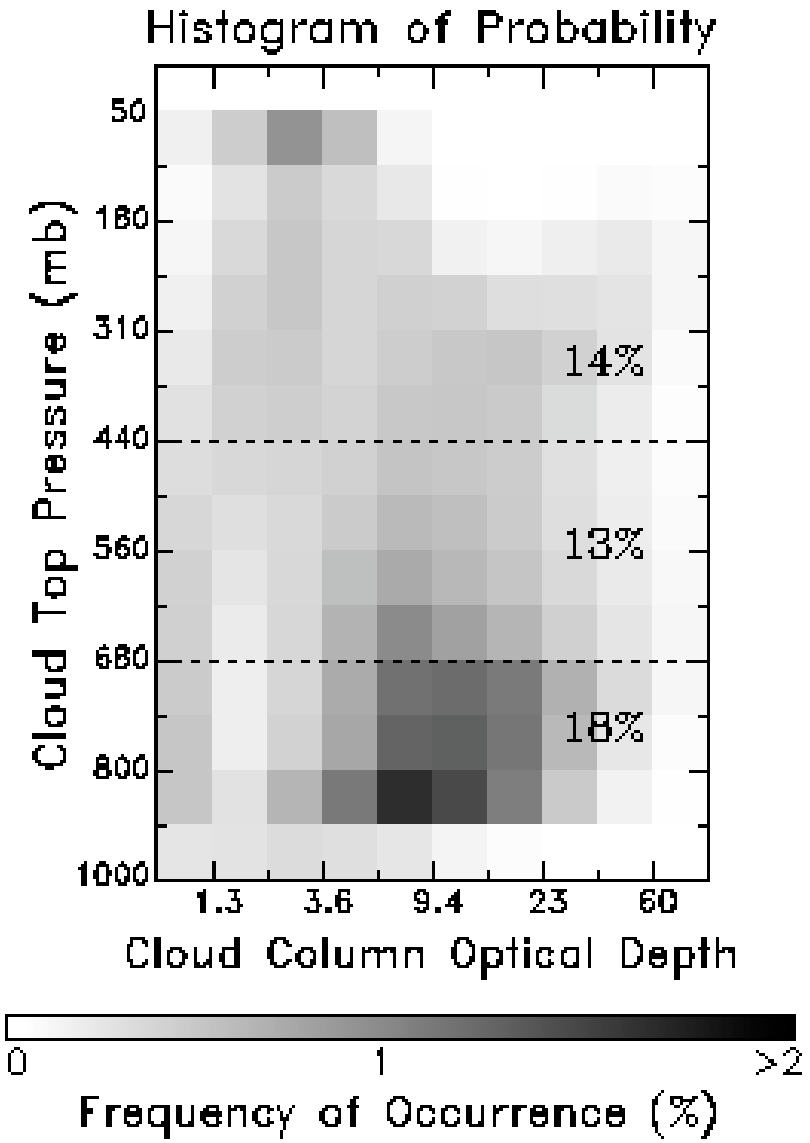


The MODIS Products of Cloud Top Pressure and Optical Depth



- A CO_2-slicing cloud top pressure is retrieved for high to mid clouds (< 700 hPa)
- Cloud top pressure for low cloud (> 700 hPa) is retrieved from the 11-μm IR channel.
- Cloud column optical depth is retrieved from the VIS (e.g., 0.64-μm) channel.
- A single-layer cloud assumption is made in the retrievals.

The ISCCP-like Bi-spectral IR-VIS Cloud Retrieval Method



- Cloud top pressure is retrieved from the IR 11-μm channel;
- Cloud column optical depth is retrieved from the VIS (e.g., 0.64-μm) channel.
- A single-layer cloud assumption is made in the retrievals.

More Motivation for This Study

- When such cirrus cloud overlapping occurs, a very high cirrus cloud top can be detected by the CO_2-slicing method. Meanwhile, the satellite-observed 11-μm thermal emission is dominated by the low cloud and transmits through the thin cirrus, which can be combined with the CO_2-slicing retrieved cirrus T_{hc} to determine the cirrus IR emissivity (ε).

Dual-layer IR Radiation Model

MODIS-observed
11-μm radiance
R

$\Rightarrow$

$$\varepsilon_{hc} = \frac{R - R'}{B(T_{hc}) - R'}$$

$\Uparrow$

High cirrus cloud: T_{hc} , ε_{hc} , τ_{hc}

Low water cloud: T_{lc} , ε_{lc} , τ_{lc}

Surface background

In our dual-layer model:

$$R' = \varepsilon_{lc} B(T_{lc}) + (1 - \varepsilon_{lc}) R_{clr}$$

In conventional single-layer model:

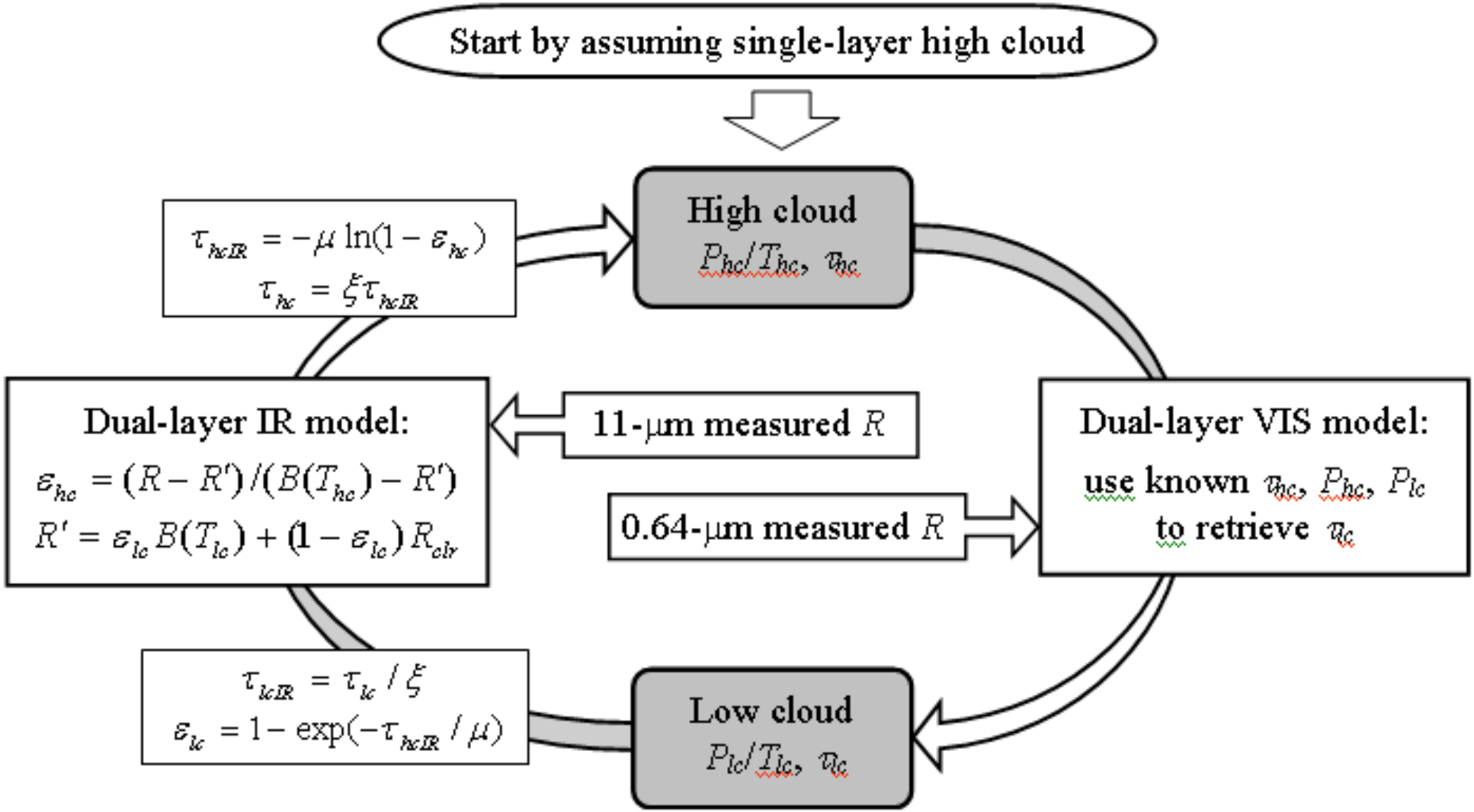
$$R' = R_{clr}$$

$\Downarrow$

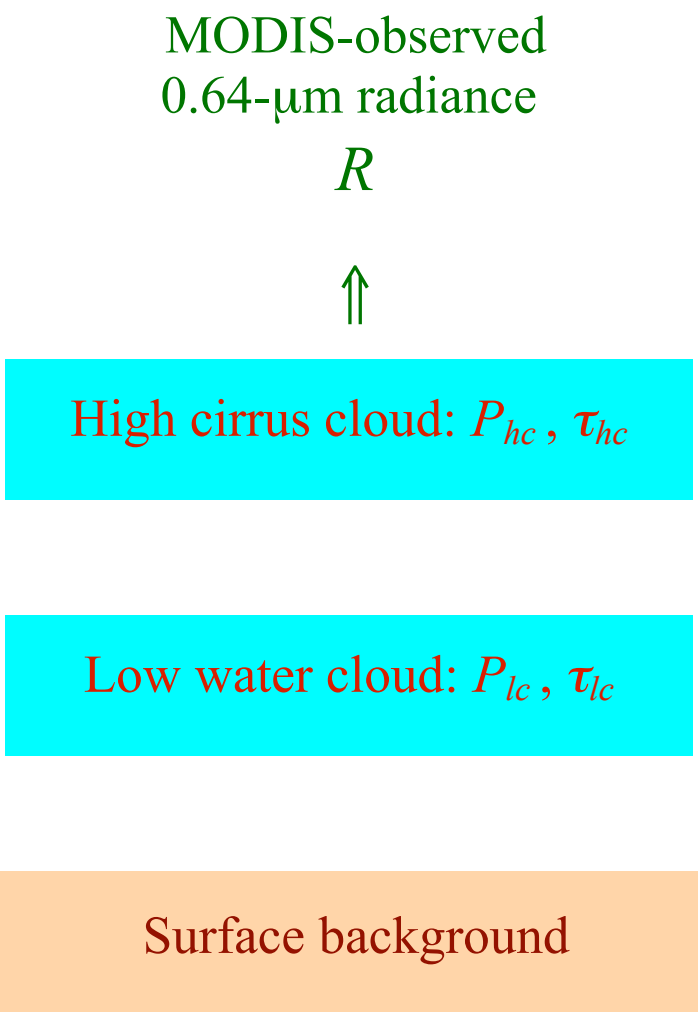
$$\tau_{hc,IR} = -\mu \ln(1 - \varepsilon_{hc})$$

$$\tau_{hc} = \xi \tau_{hc,IR}$$

Schematic Diagram of our Dual-layer IR and VIS Retrieval Algorithm



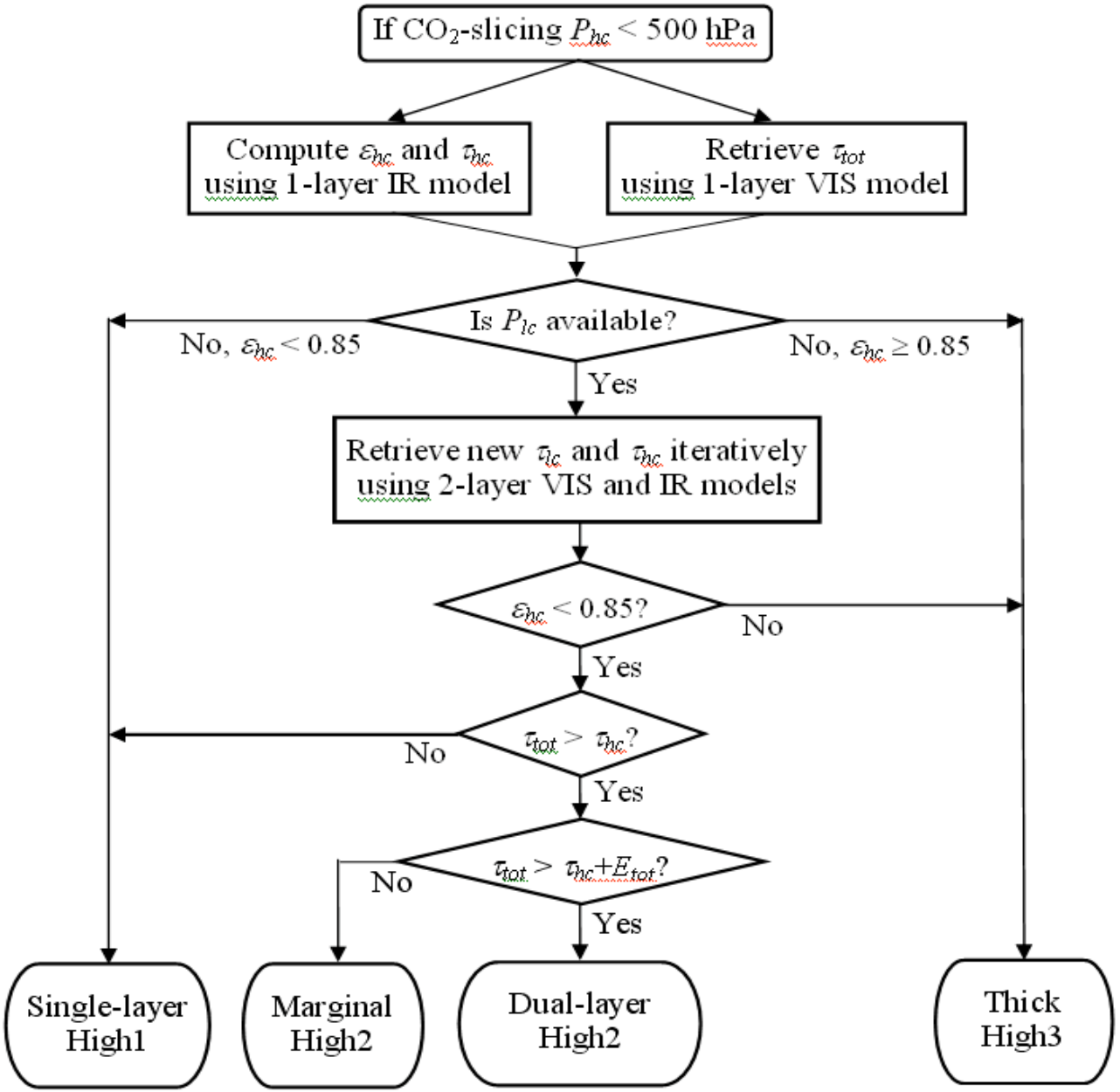
Dual-layer VIS Radiation Model



⇒

- Use known τ_{hc}, P_{hc}, and P_{lc} to retrieve τ_{lc} by comparing the MODIS-observed VIS reflectance to lookup-table reflectances generated using the dual-layer model.
- Various sets of lookup tables are generated with:
  P_{hc} = 100, 300, 500 hPa,
  τ_{hc} = 0.01, 0.25, 0.5, 1, 2, 3, 5,
  P_{lc} = 500, 700, 900, 1000 hPa,
  τ_{lc} = 0.05, 1, 2, 3, 4, … 100.
- An ice poly-crystal model (r_e = 30 μm) for high cirrus cloud; and a water-cloud model (r_e = 10 μm) for low cloud.

Schematic Flow Chart for the Retrieval Procedure



Dual-layer Retrieval Application and Demonstration

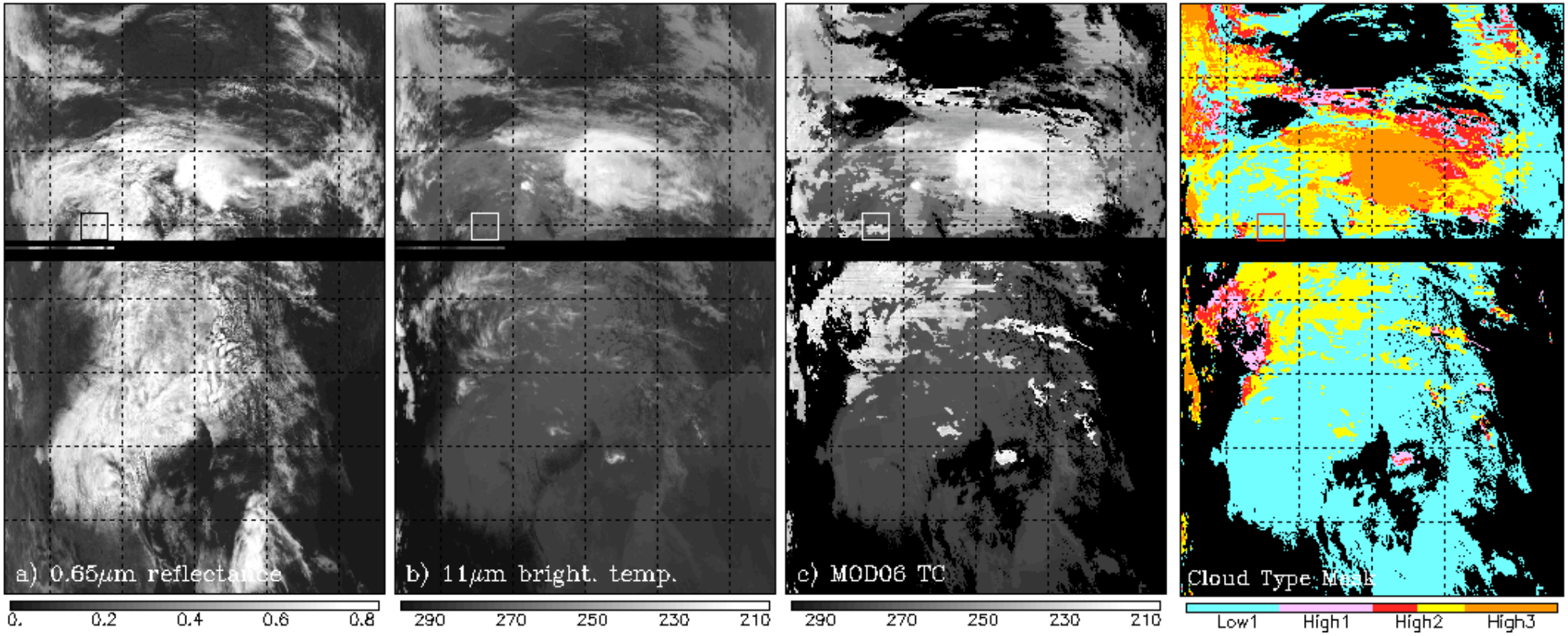
θ The MODIS granule (5-minute segment) is obtained on April 2, 2001 (1715 UTC).

MODIS 0.65-μm reflectance

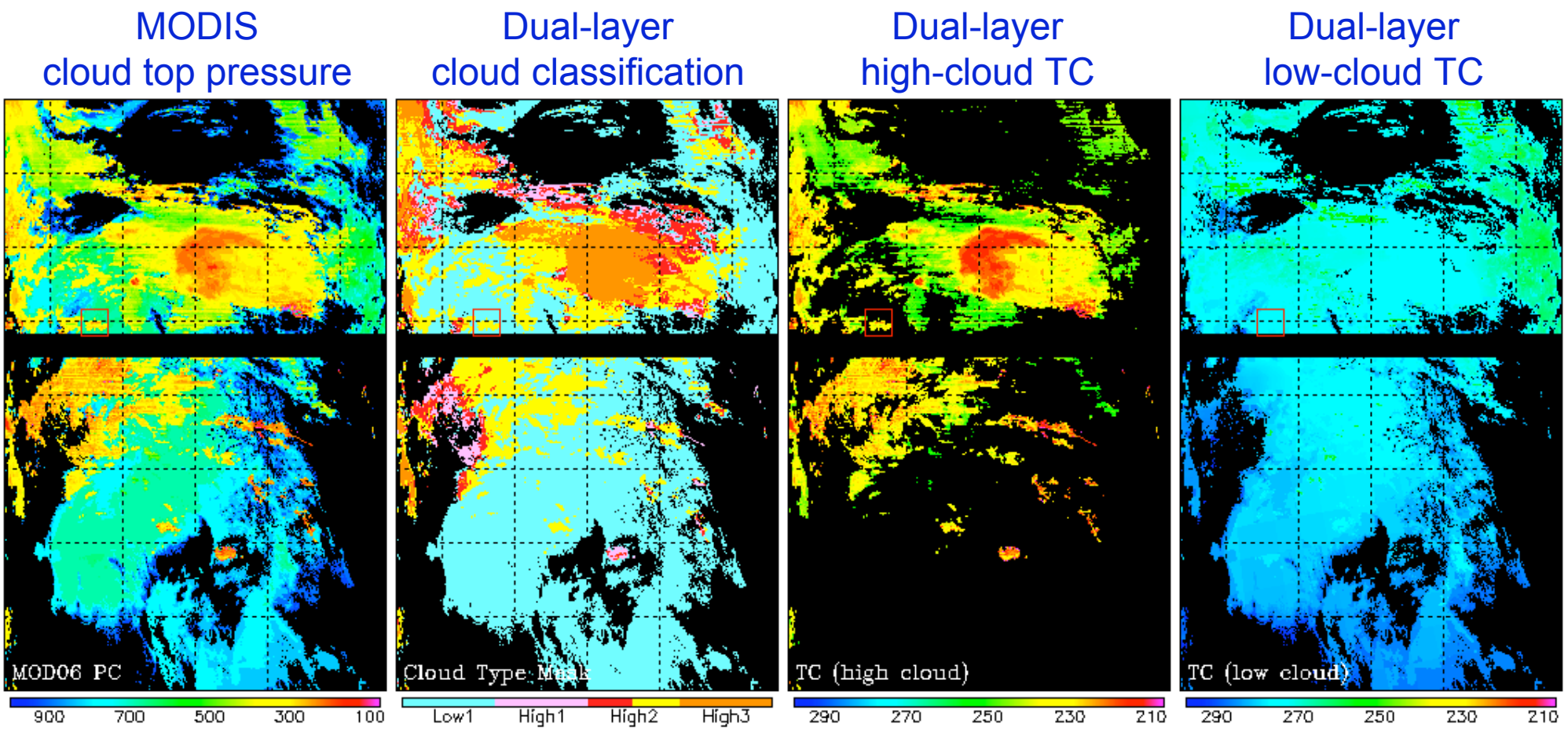
MODIS 11-μm reflectance

MODIS cloud top temperature

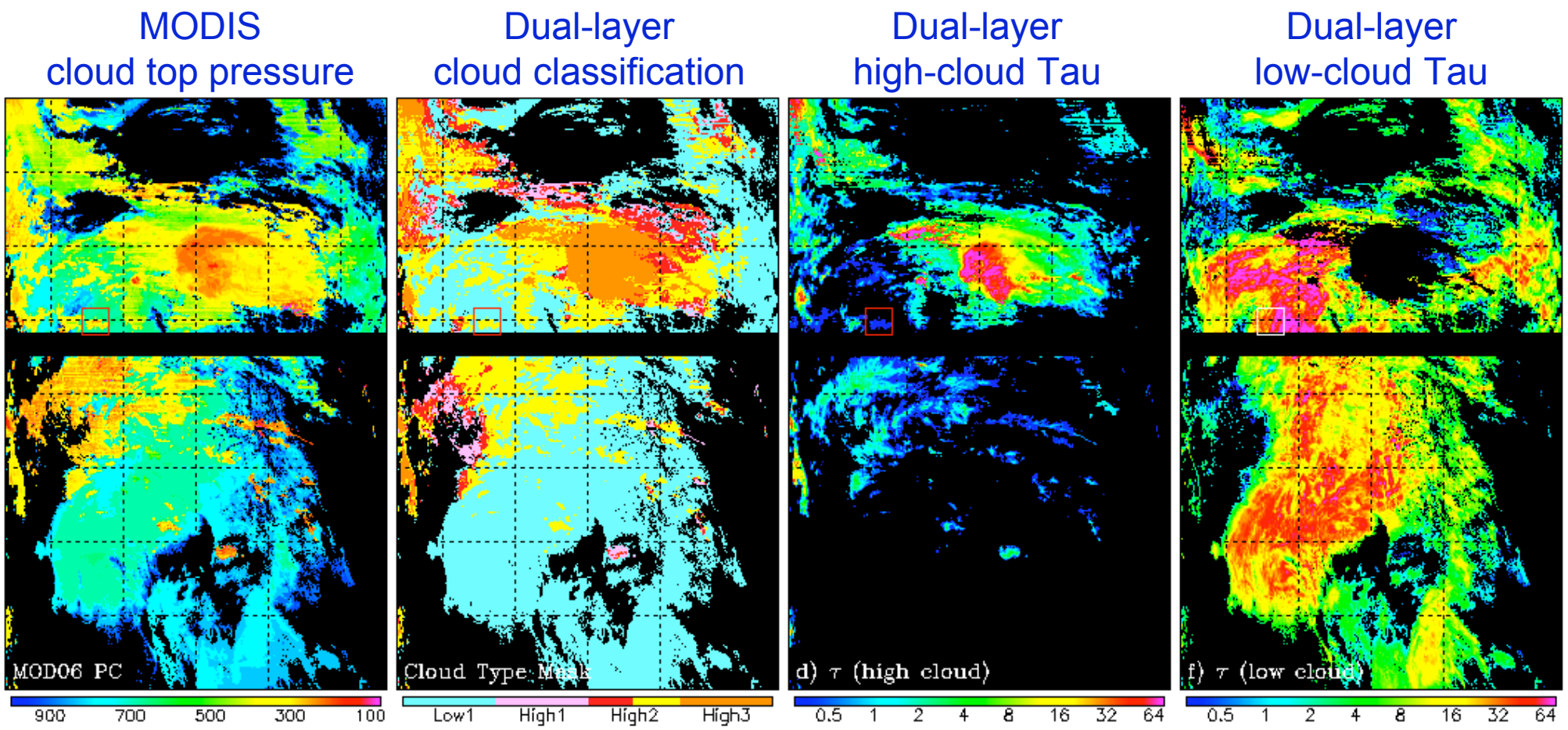
Dual-layer cloud classification



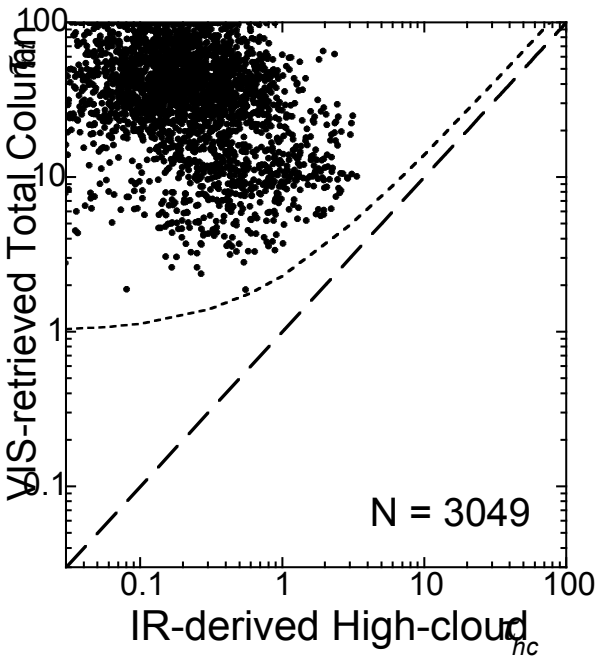
Dual-layer Retrievals of High and Low Cloud Temperatures

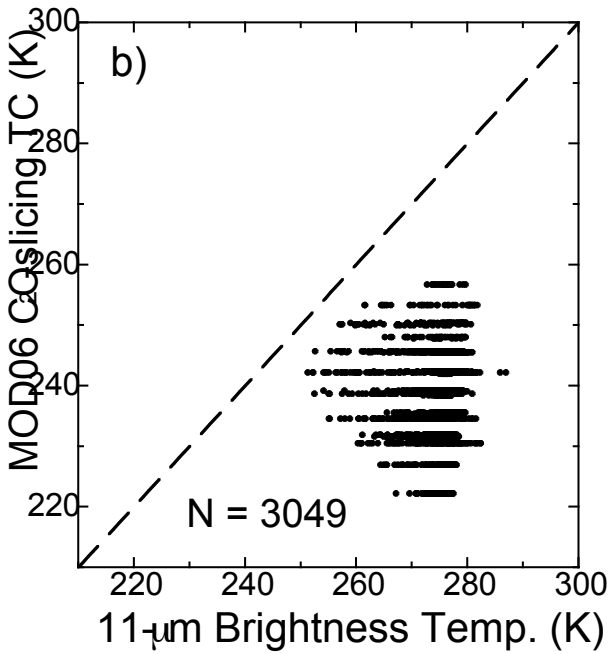


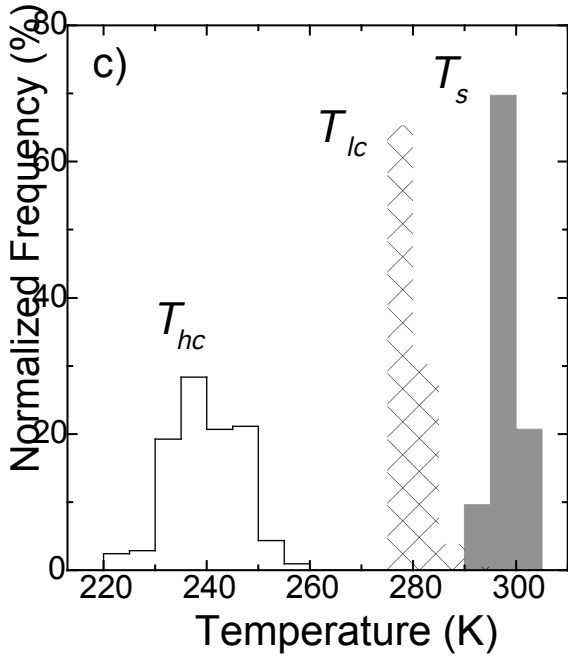
Dual-layer Retrievals of High and Low Cloud Optical Depths



Analysis of the Dual-layer Cloud Properties







- The dotted line is for

$$\tau_{tot} = \tau_{hc} + E_{tot}$$

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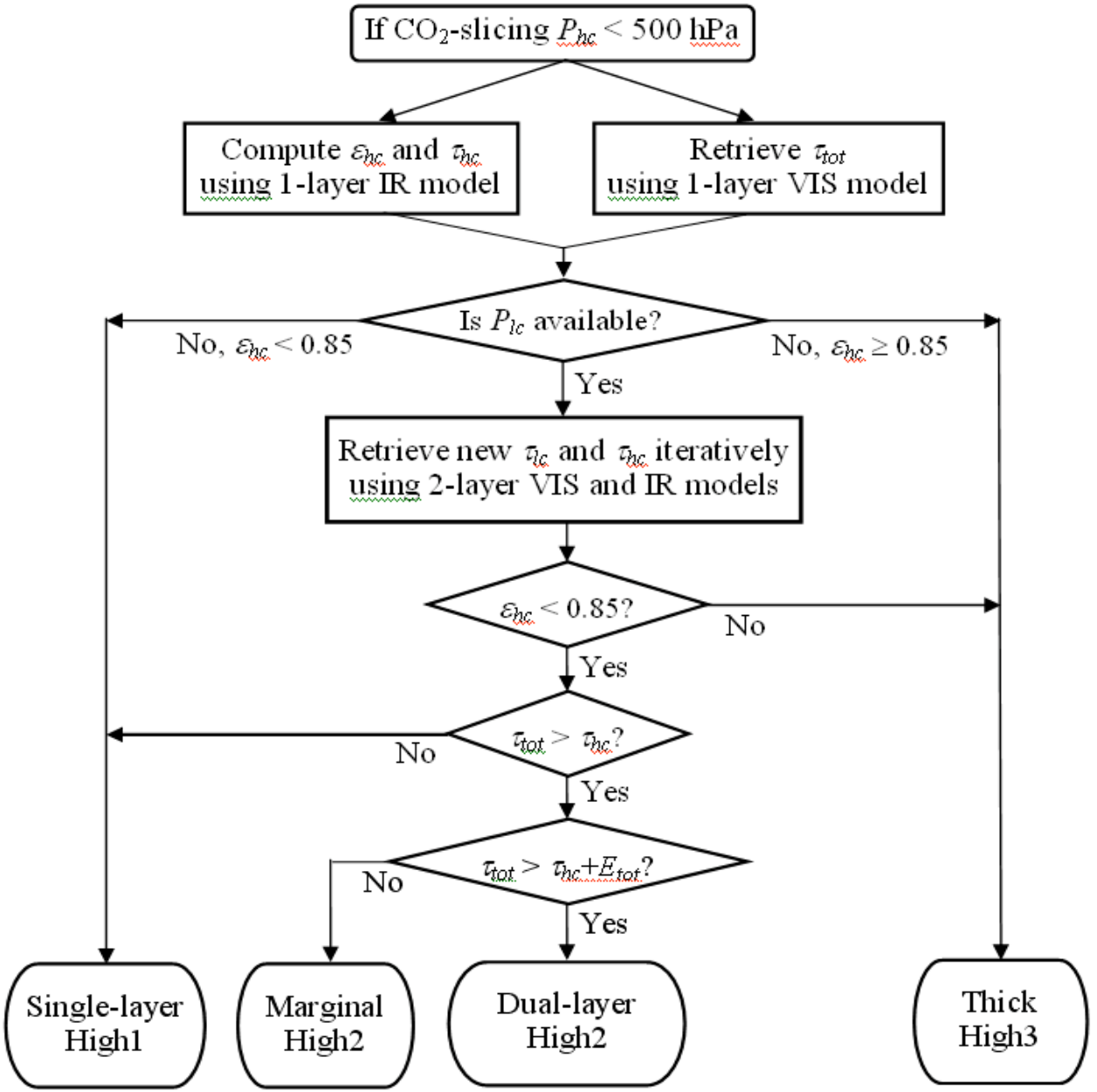
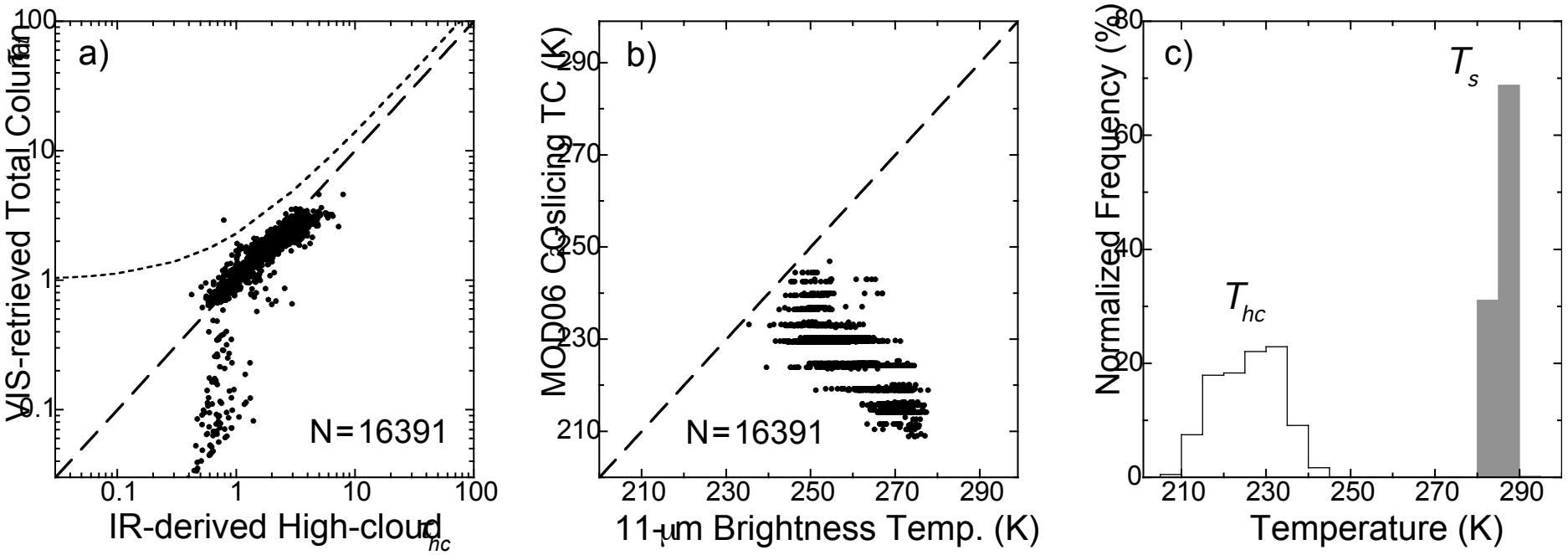


Analysis of the Single-layer Cloud Properties

θ A single-layer cloud system observed on March 6, 2001 (1735 UTC) over SGP site.



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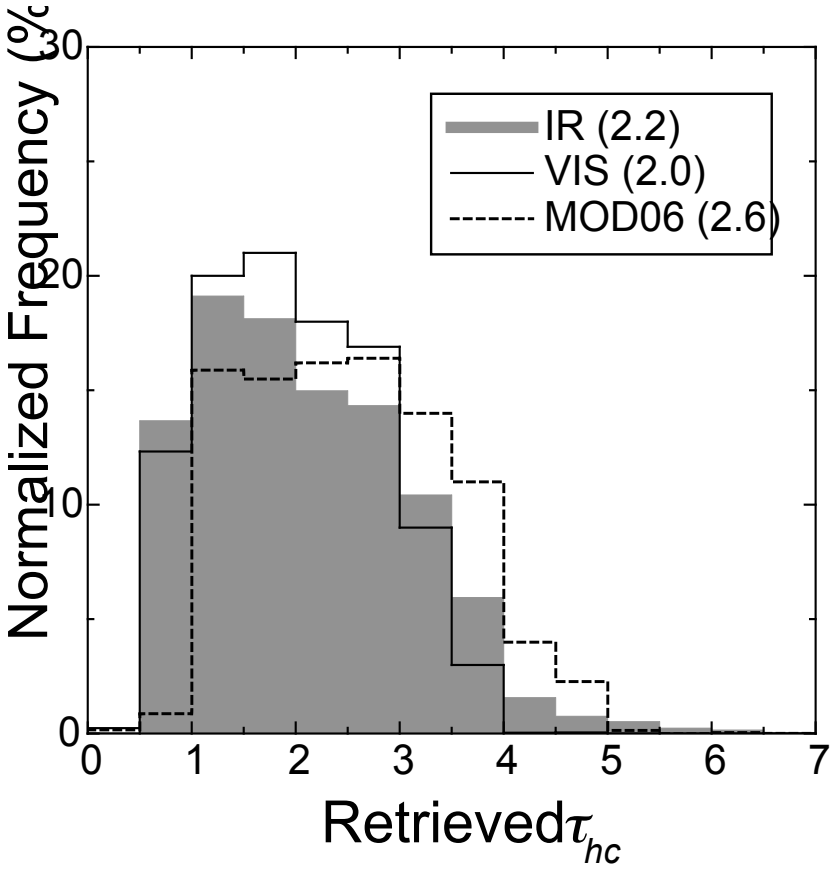
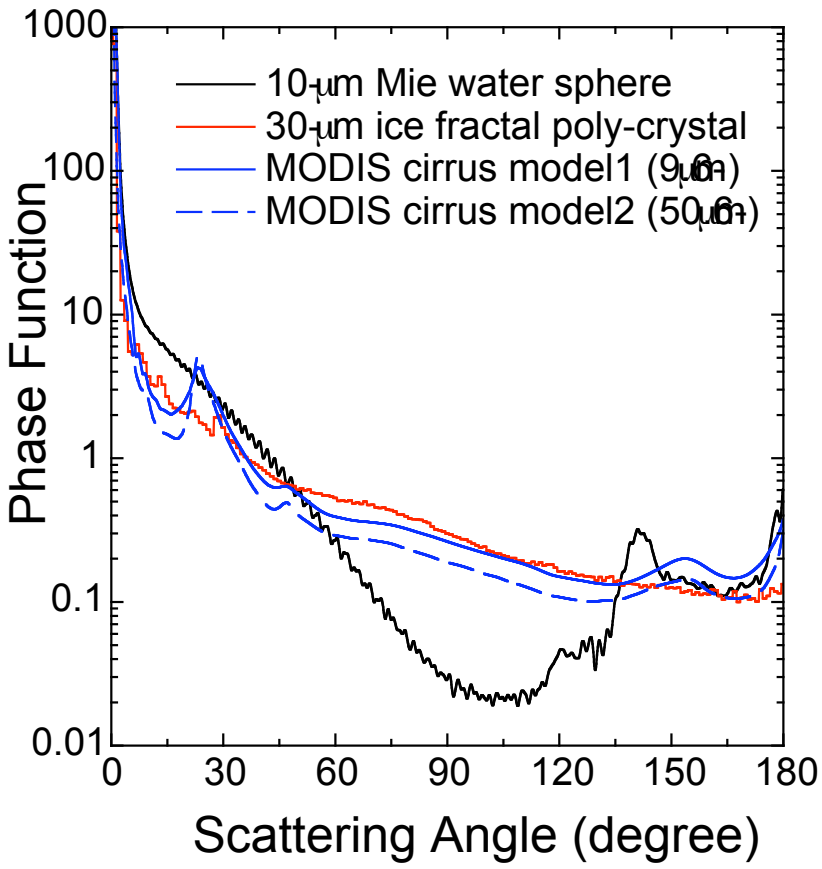
$$\tau_{tot} = \tau_{hc} + E_{tot}$$

Comparisons of the Retrieved Single-layer Cloud Optical Depths





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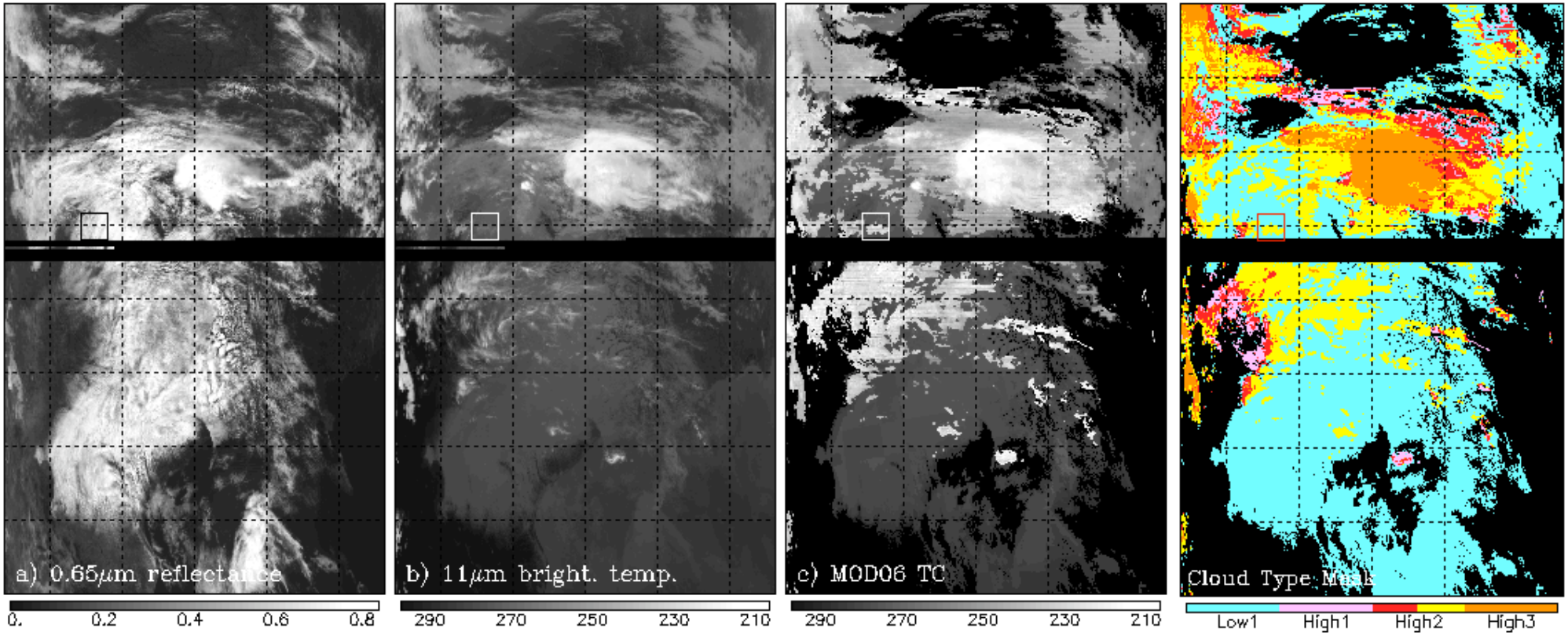
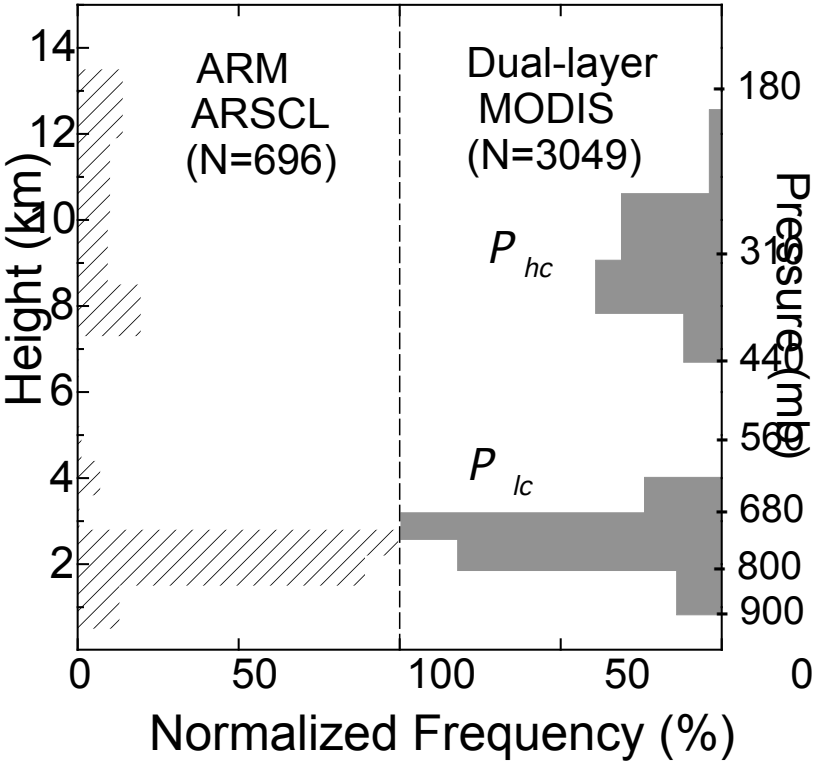
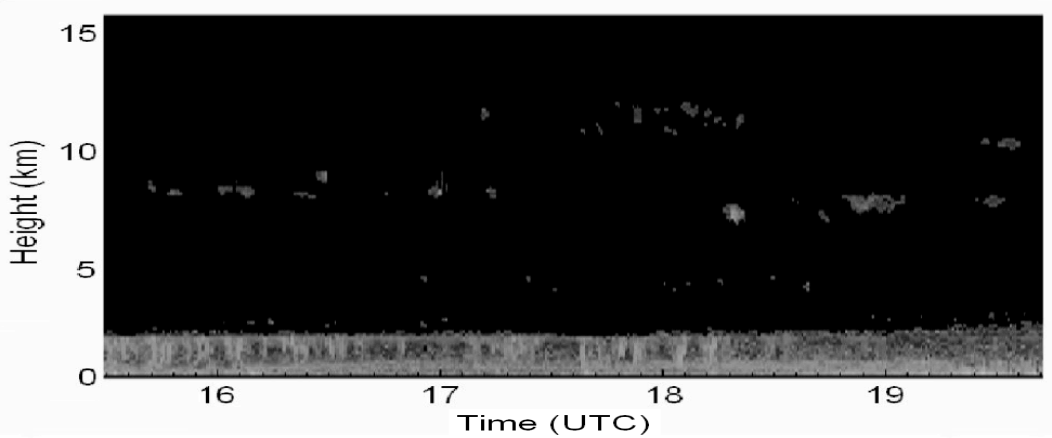


Verification of the Dual-layer Cloud System

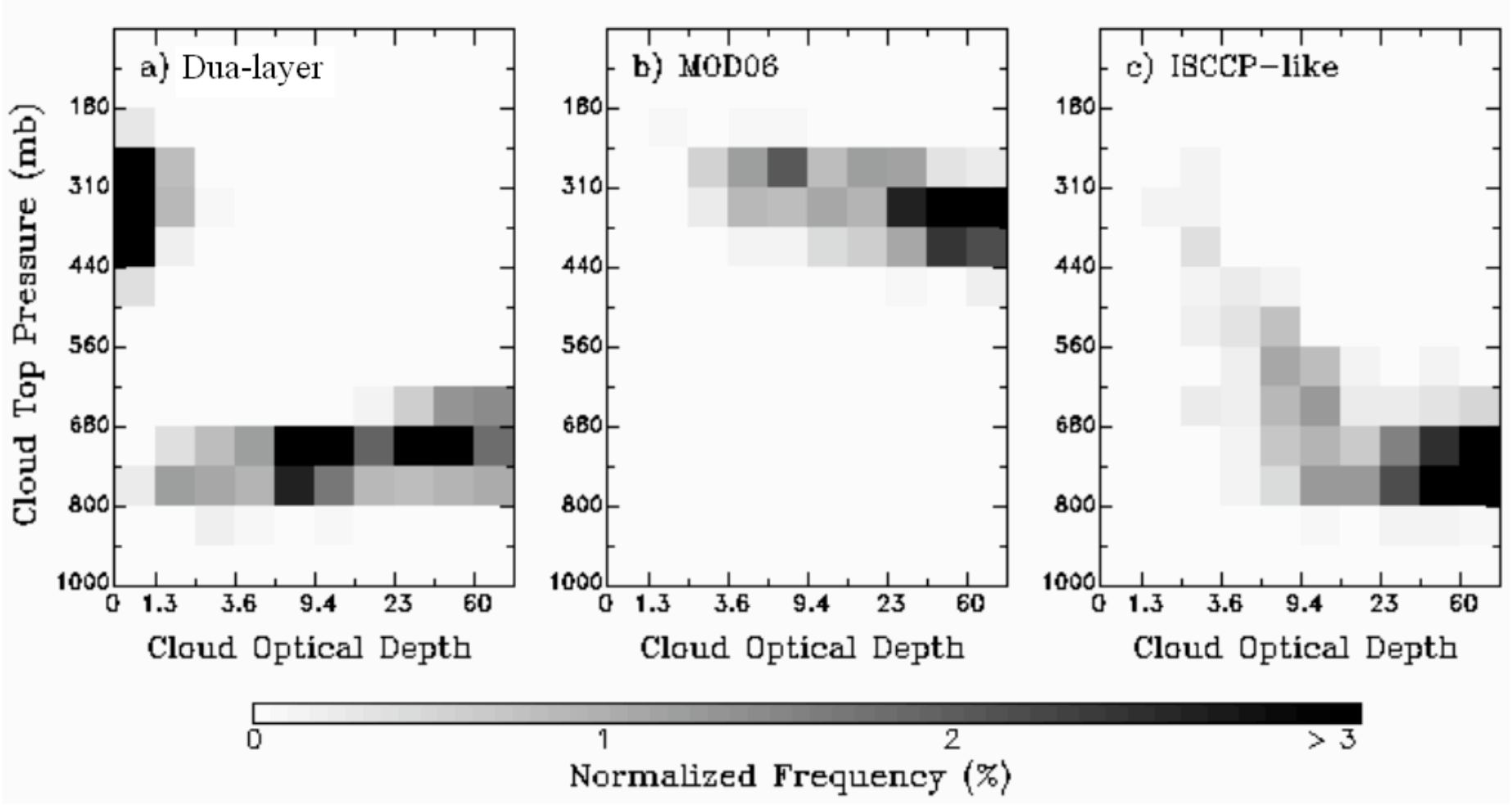
- The ARM Active Remote-Sensed Cloud Locations (ARSCL) Value-Added Product (Clothiaux et al. 2000) retrieves cloud boundaries from combined measurements of a 35-GHz millimeter-wave cloud radar (MMCR), a vertical-pointing laser ceilometer, a microwave radiometer, and a micropulse lidar.



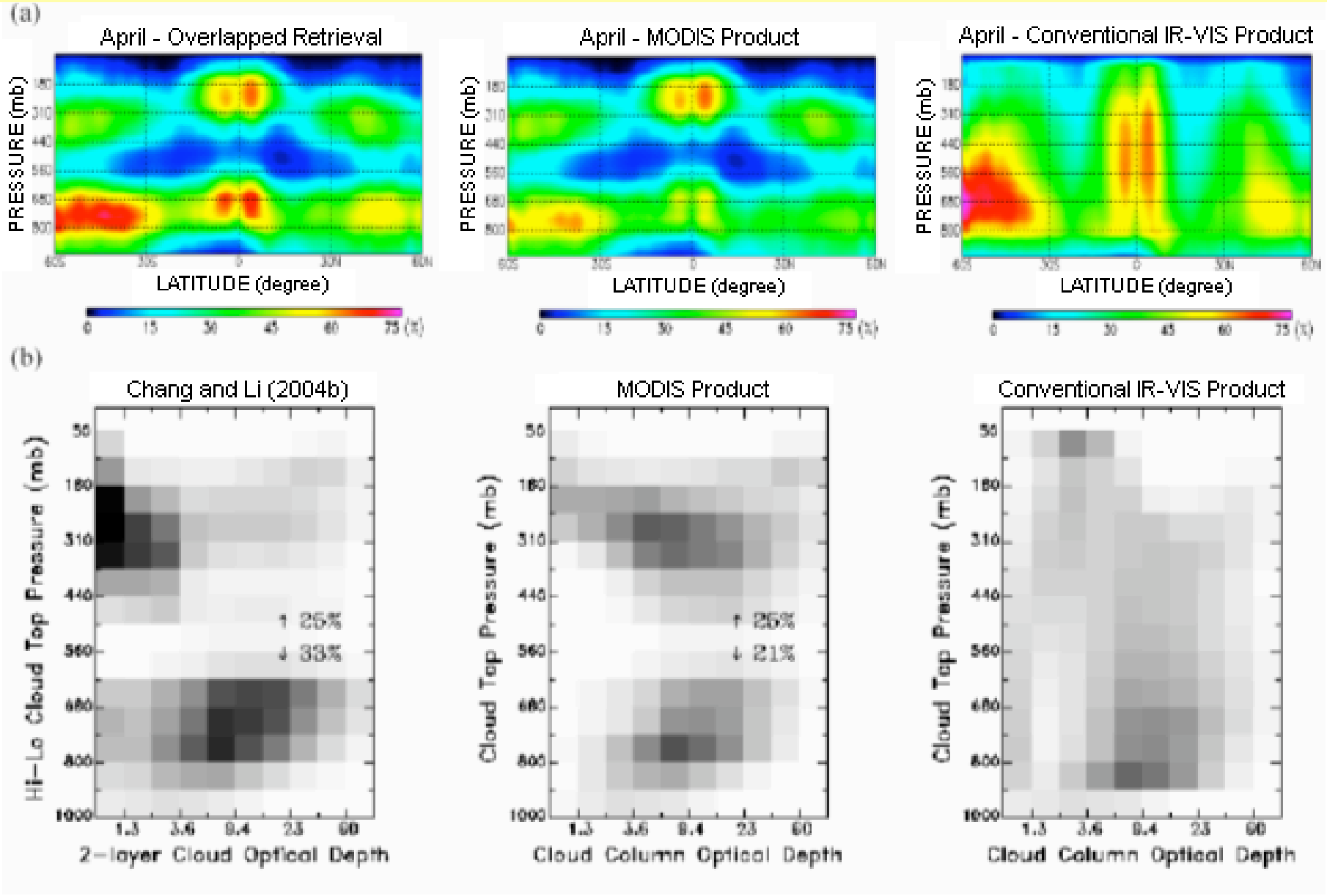


The MMCR reflectivity data
(J. Mace, University of Utah)

Implication of Three Different Retrieval Algorithms (from the overlapped cloud pixels)

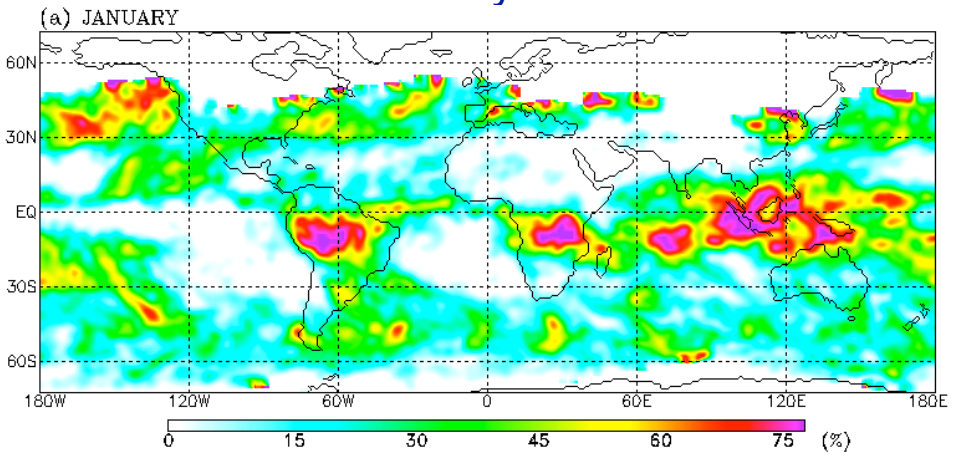


Implication of Three Different Retrieval Algorithms (from the global cloud pixels)

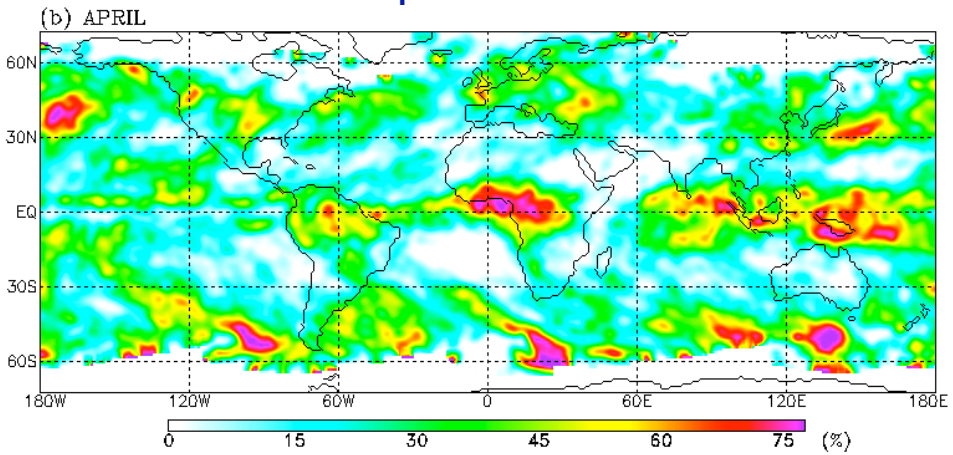


Total High Cloud Amount (Single-layer + Overlapped + Thick)

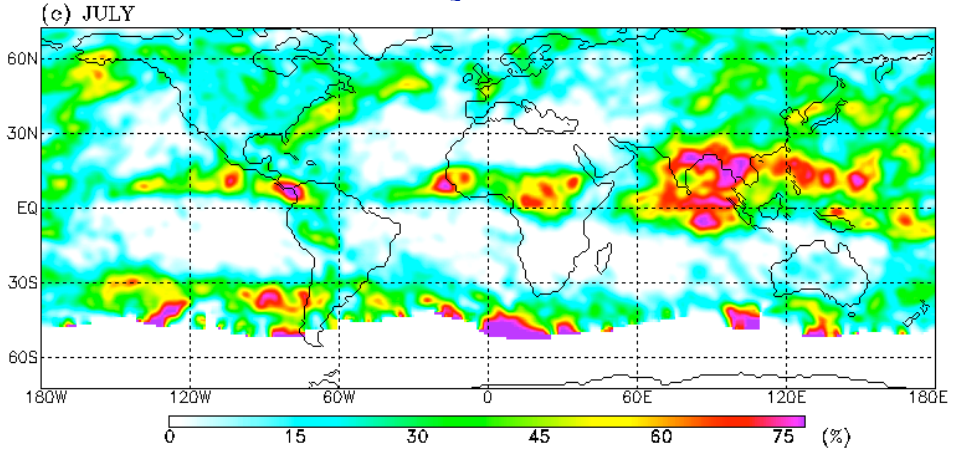
January 2001



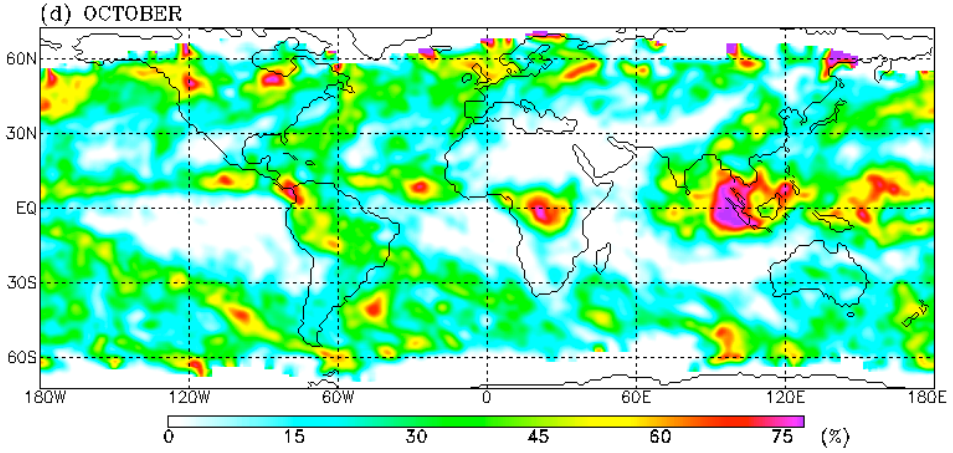
April 2001



July 2001

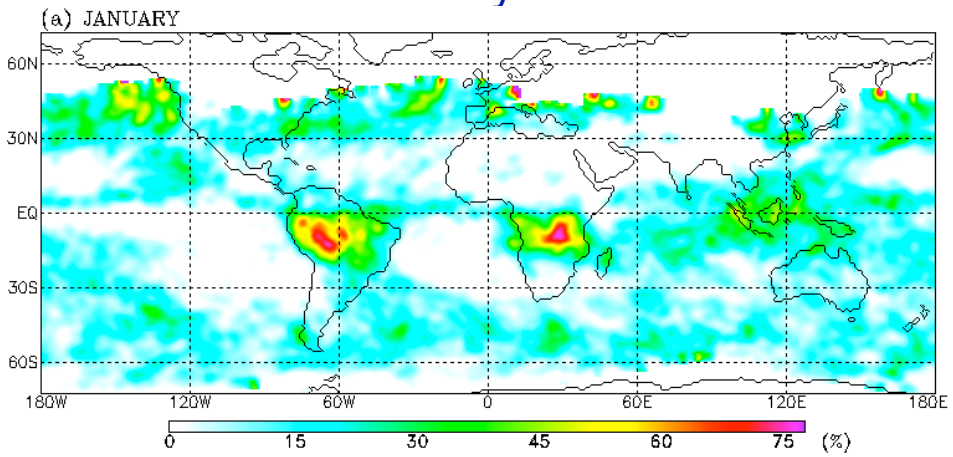


October 2001



Overlapped Cloud Amount

January 2001



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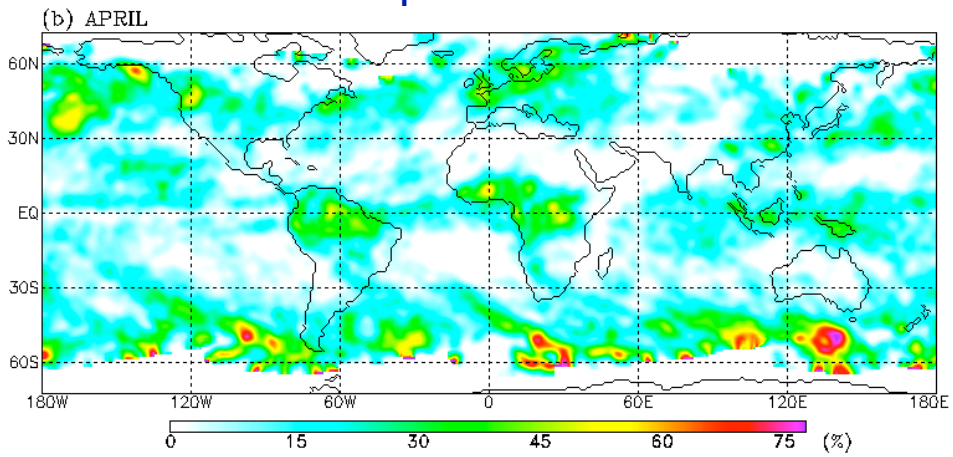

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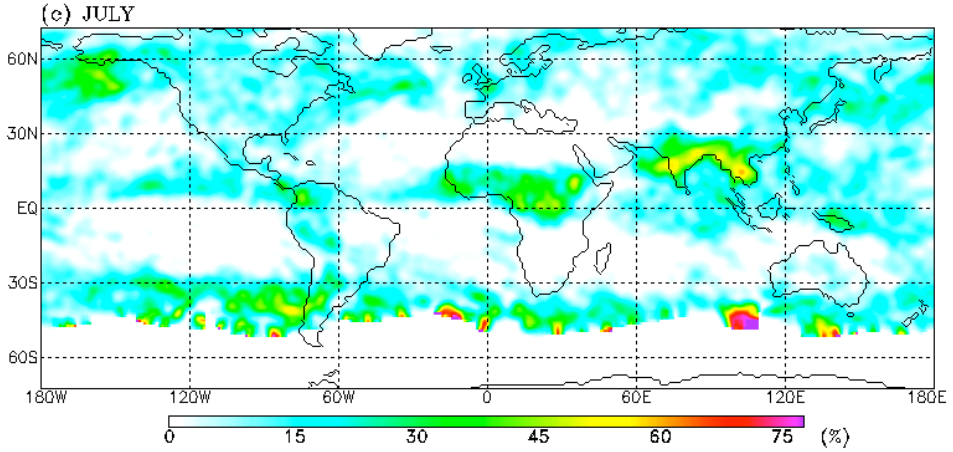

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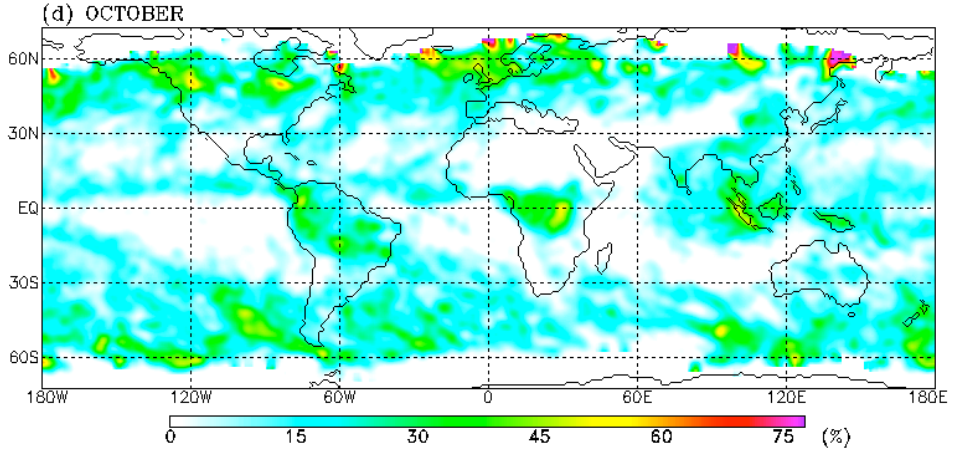
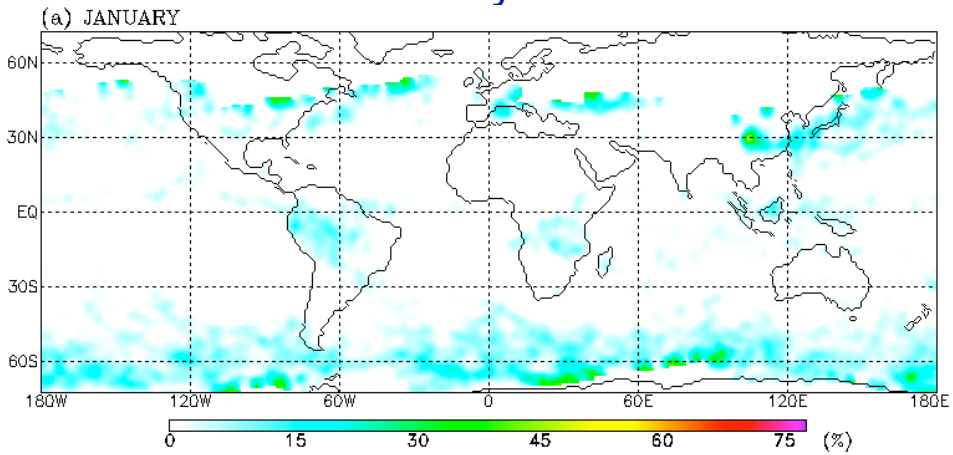


Mid Cloud Amount

January 2001



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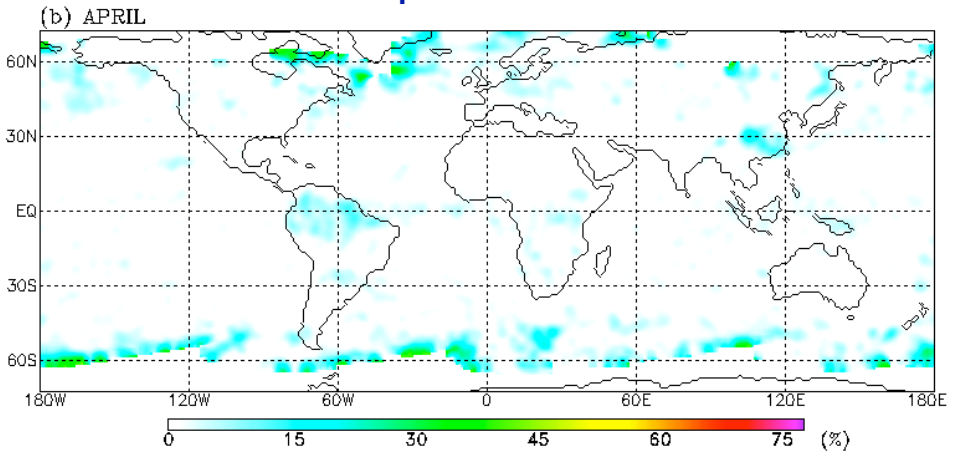

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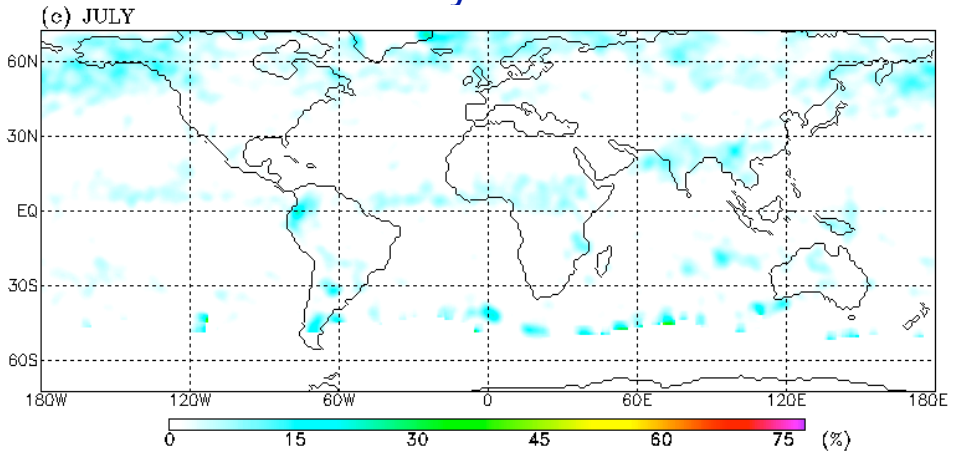

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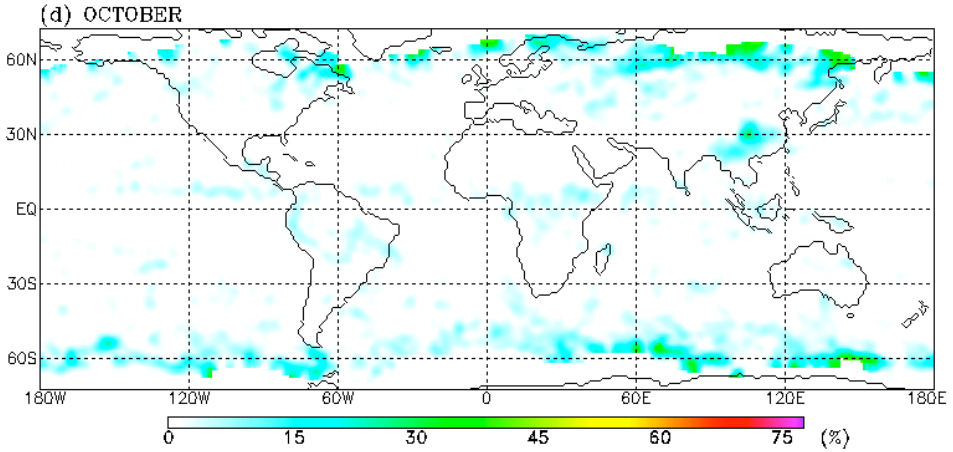
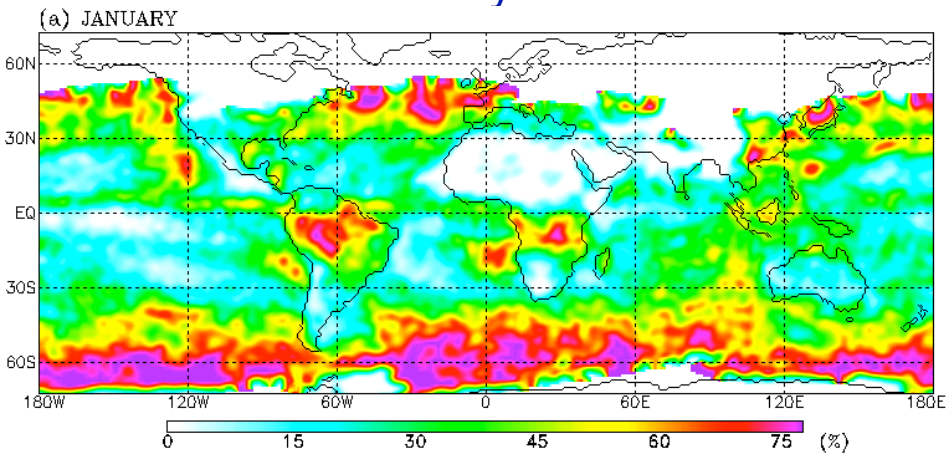


Total Low Cloud Amount (Single-layer + Overlapped)

January 2001



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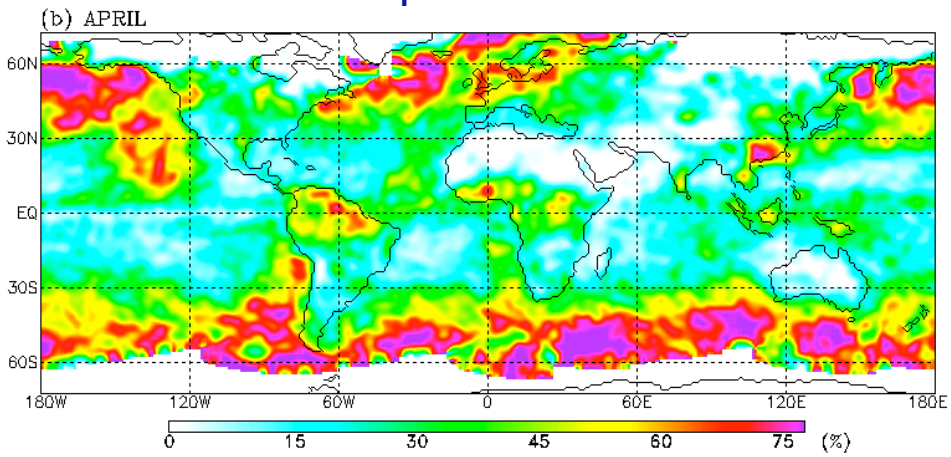
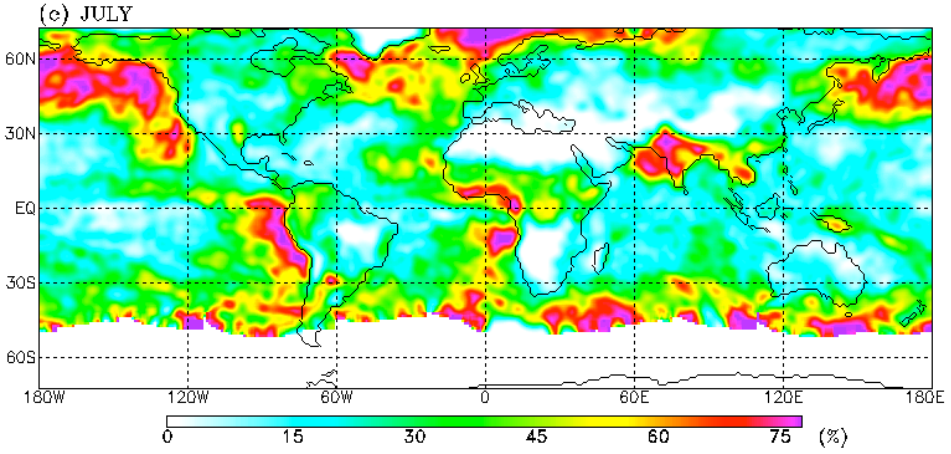


July 2001



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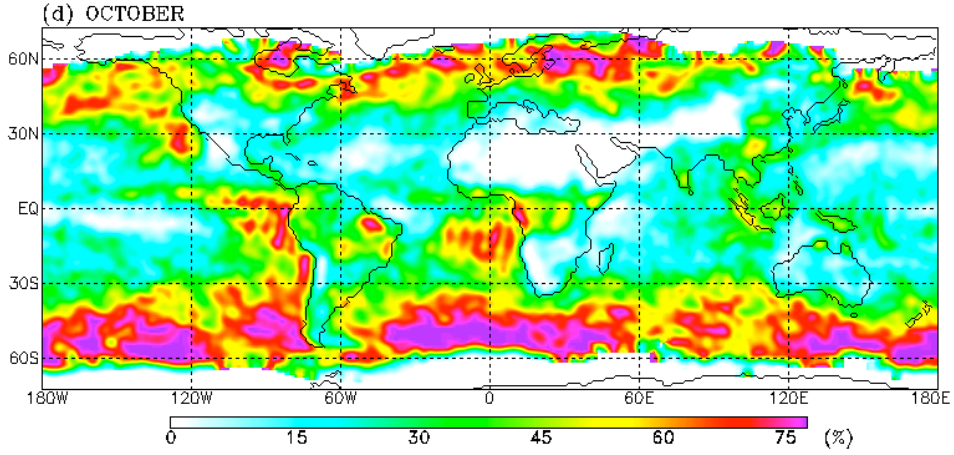
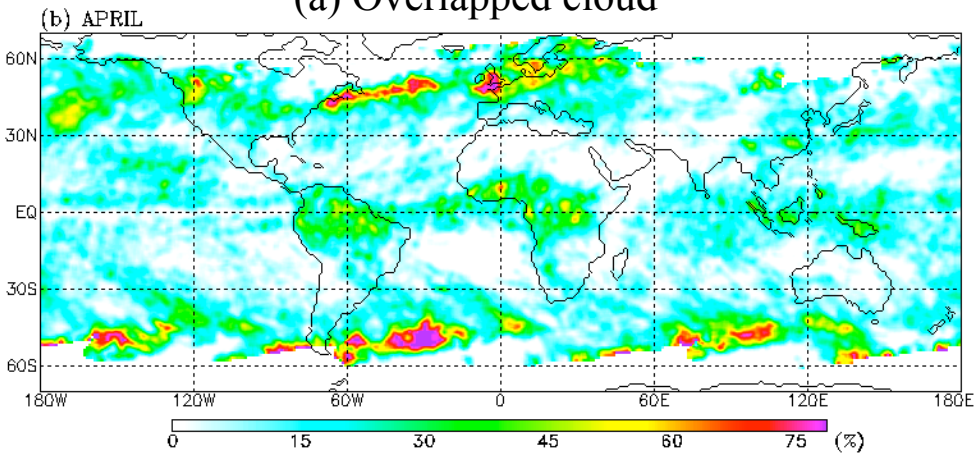
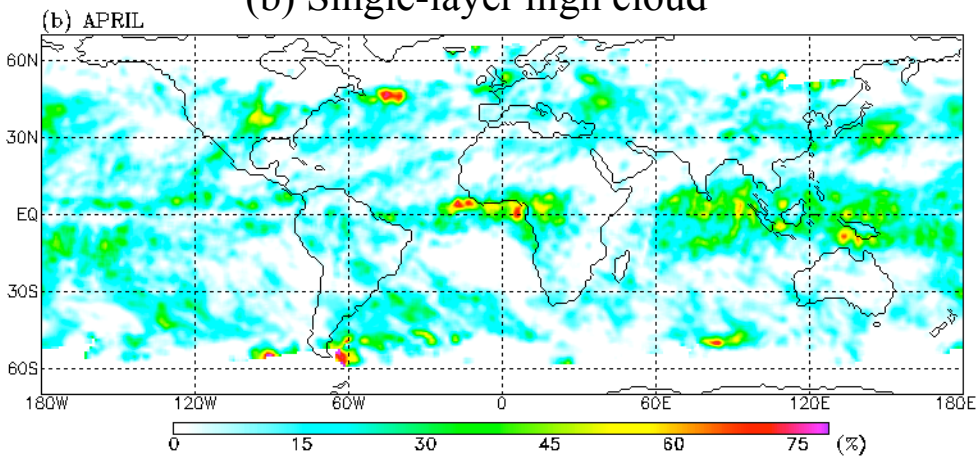


Distributions of Cloud Amounts for Different Cloud Types

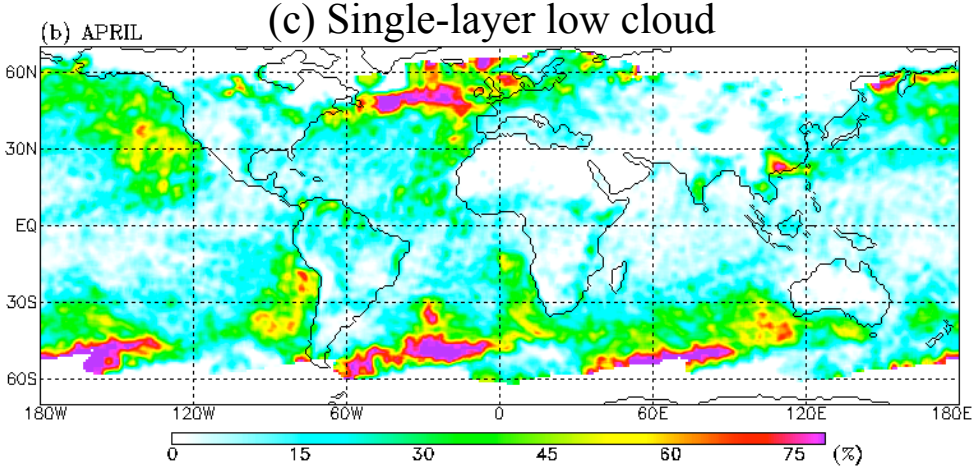
(a) Overlapped cloud



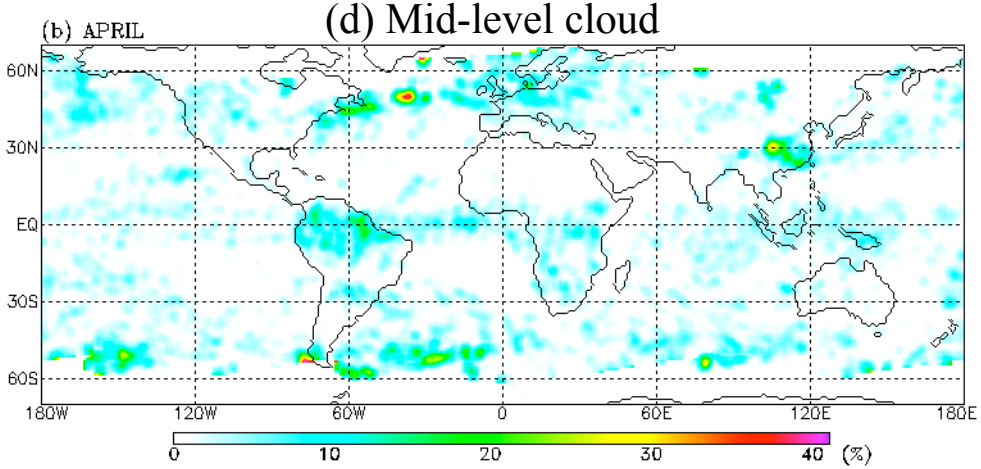
(b) Single-layer high cloud



(c) Single-layer low cloud

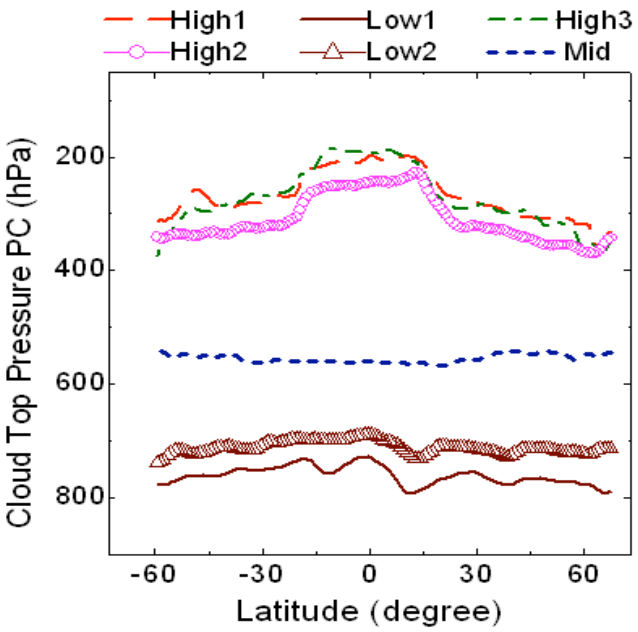


(d) Mid-level cloud

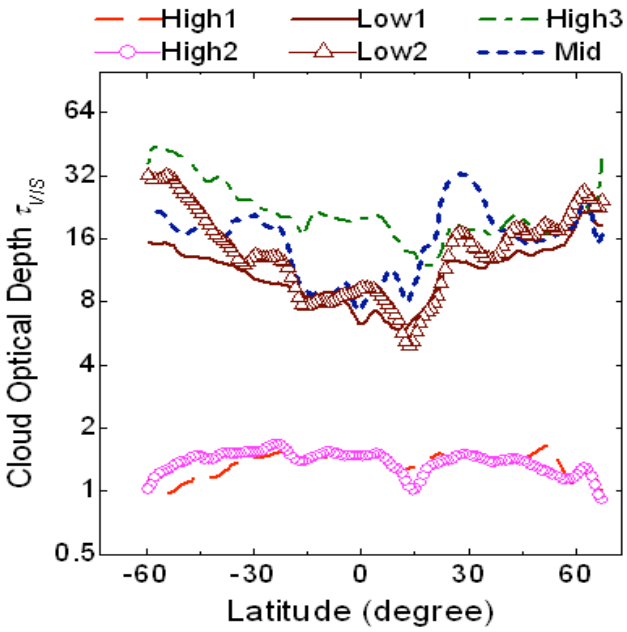


Latitudinal Distributions of the Retrieved Cloud Properties

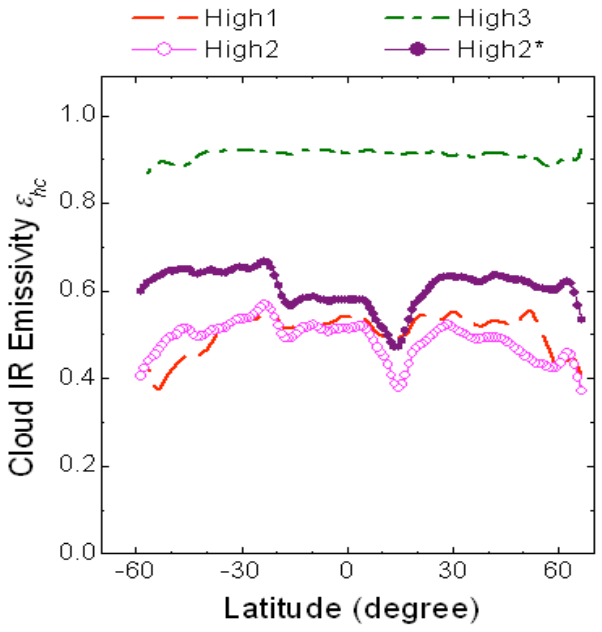
Cloud Top Pressure



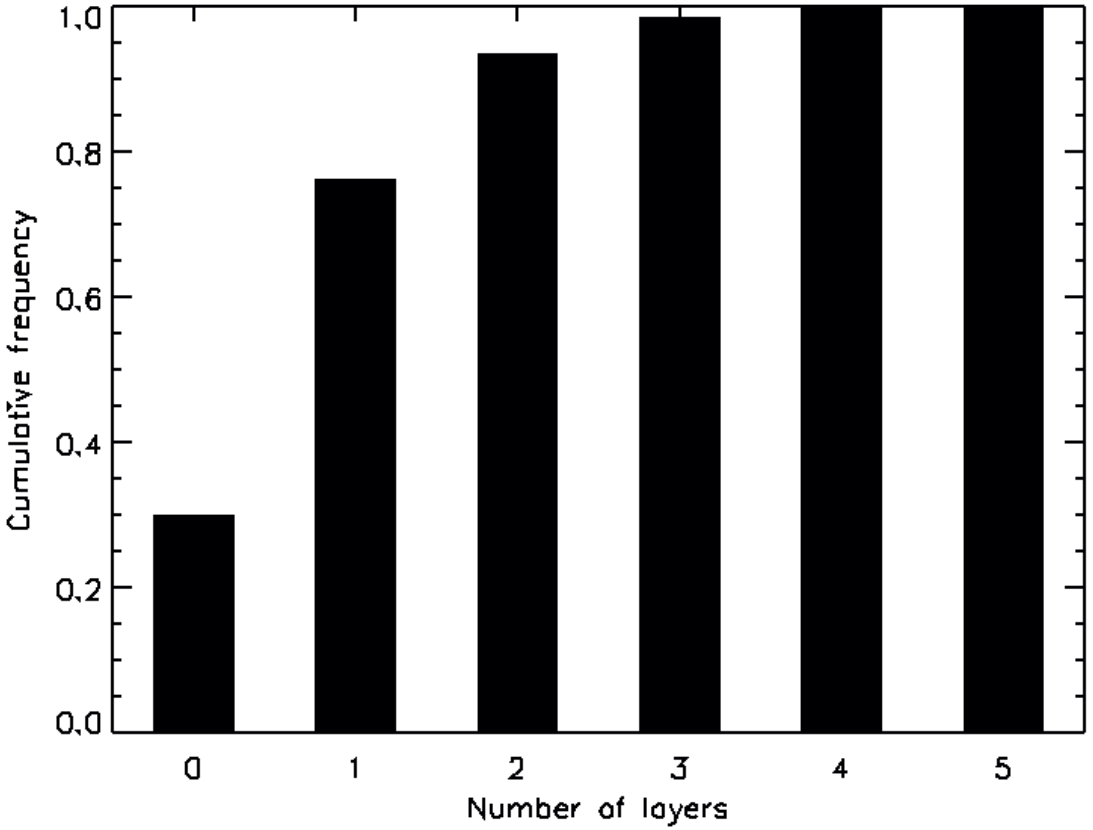
Cloud VIS Optical Depth



Cloud IR Emissivity



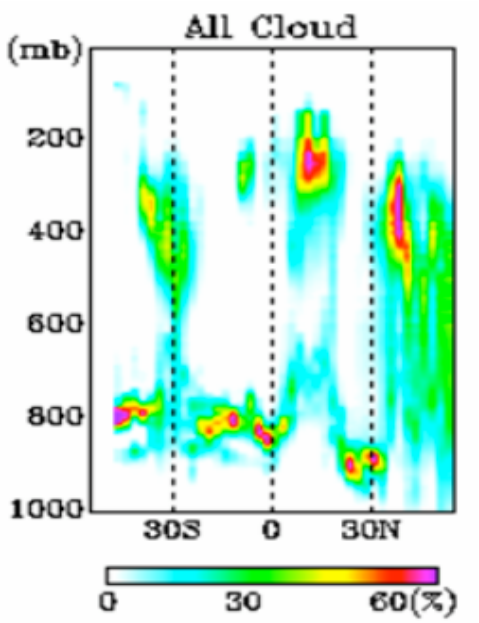
Comparisons of Global Cloud Layer Statistics with GLAS Data



Cumulative frequency of global cloud layer detected by GLAS lidar (courtesy of James Spinhirne, NASA GSFC)

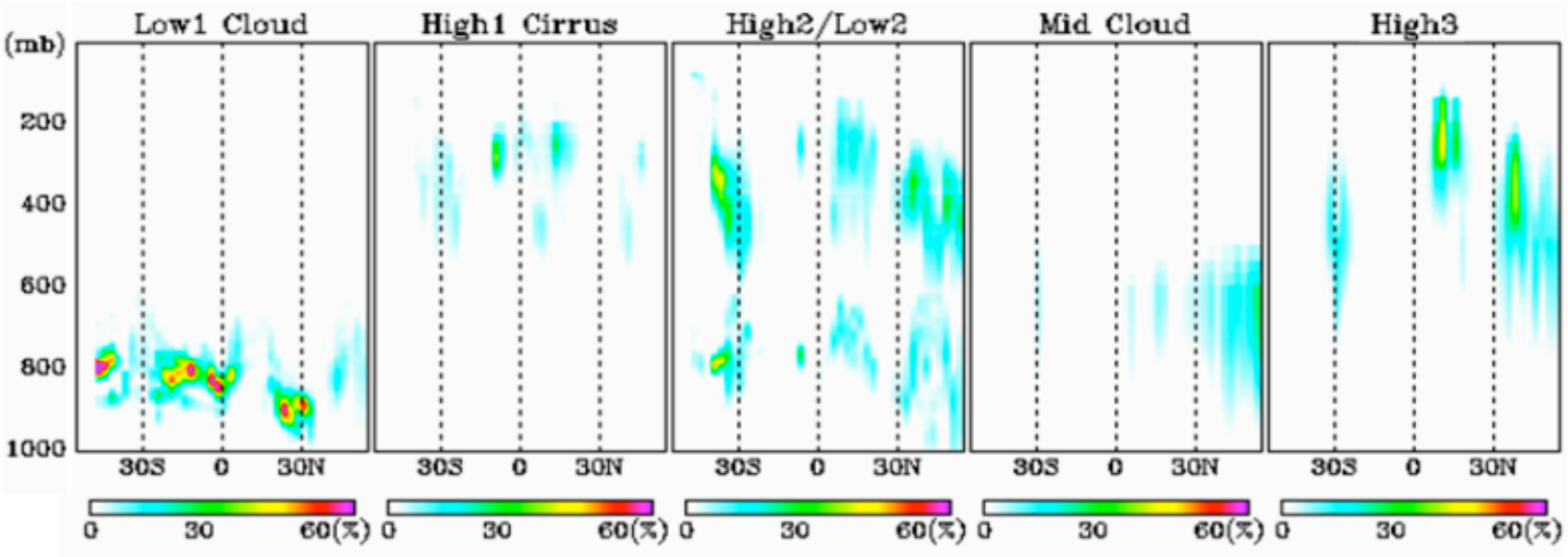
- From the space-borne Geoscience Laser Altimeter System (GLAS) data, single and two-layer clouds account for ~90% of all clouds.
- Their results:
  35% of clouds are multi-layer clouds
- Our results:
  28% of clouds are dual-layer clouds

Estimation of Cloud Vertical Structure



- Cloud layer profiles derived for a meridional band at between 117.5°W-120°W.

$$Z_{Top} - Z_{Base} = a + bT_c + c\tau_c^{\alpha}$$



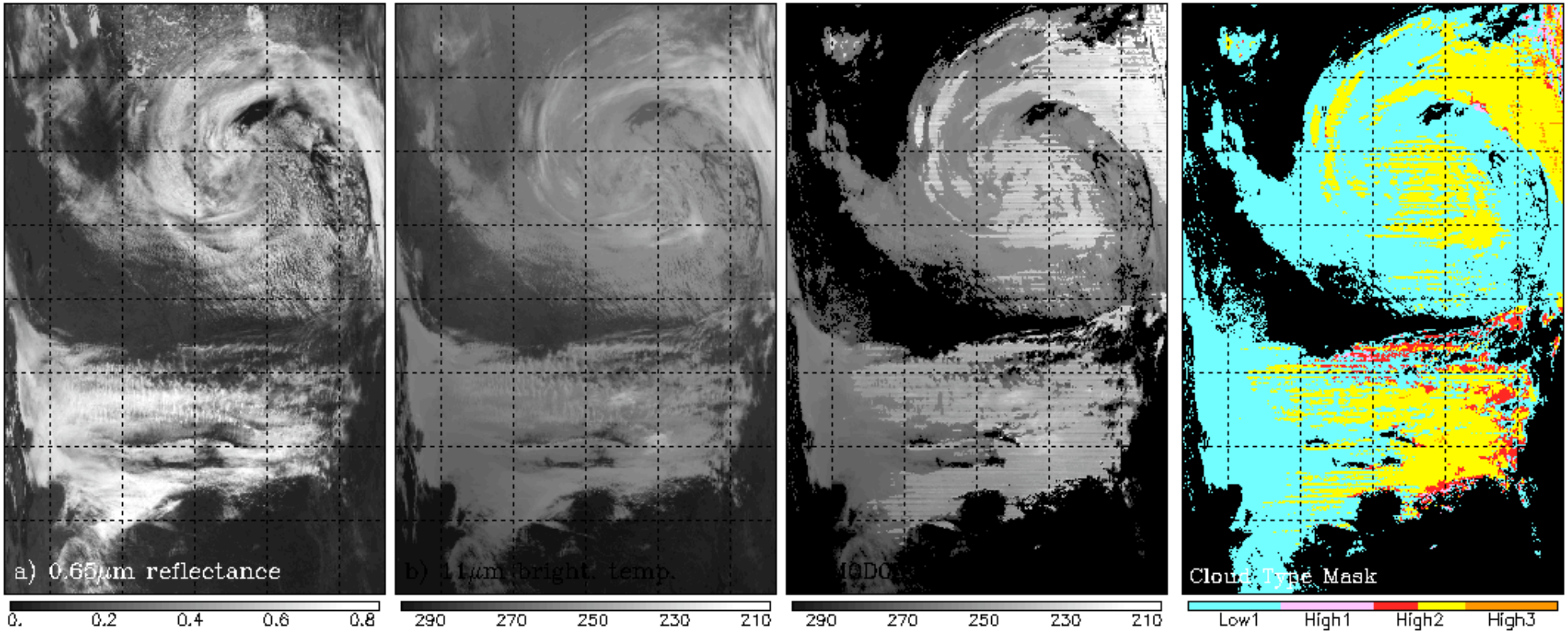
Dual-layer Retrieval Analysis

MODIS
0.65-μm reflectance

MODIS
11-μm reflectance

MODIS
cloud top temperature

Dual-layer
cloud classification



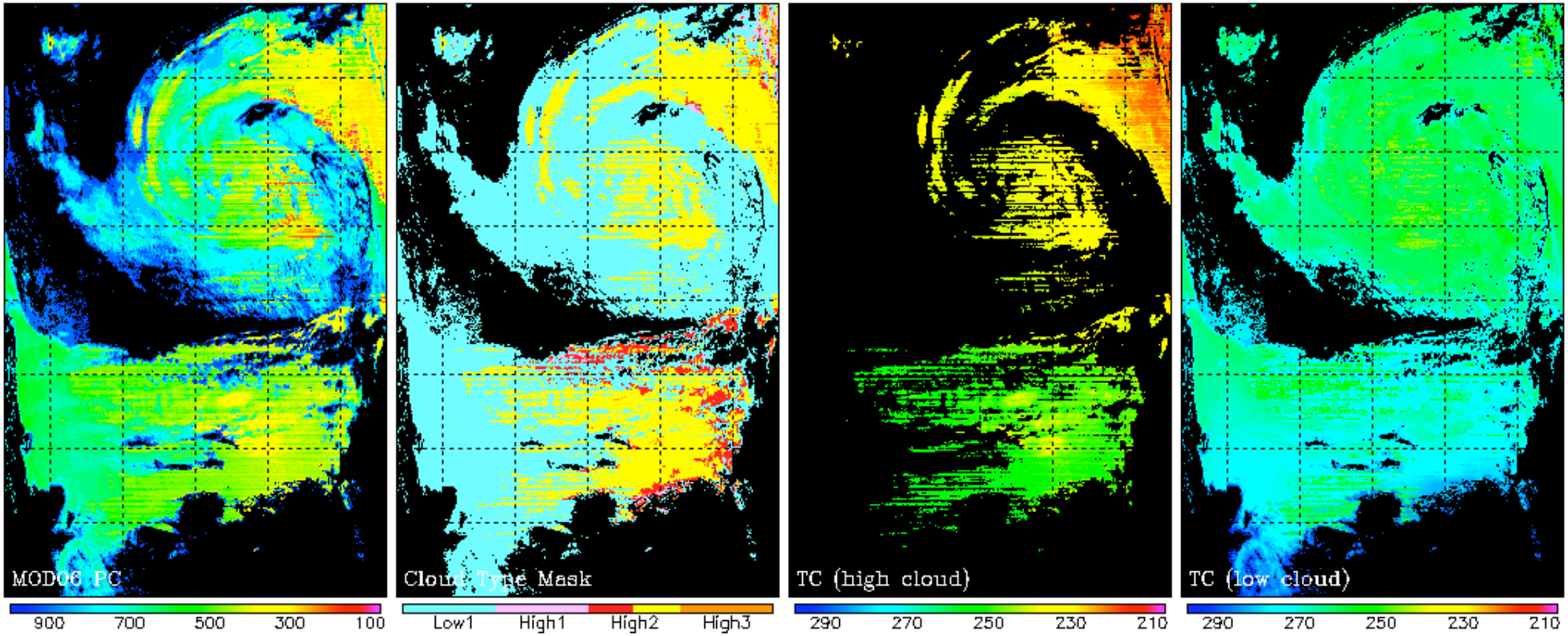
Dual-layer Retrievals of High and Low Cloud Temperatures

MODIS
cloud top pressure

Dual-layer
cloud classification

Dual-layer
high-cloud TC

Dual-layer
low-cloud TC



Dual-layer Retrievals of High and Low Cloud Optical Depths

MODIS
cloud top pressure

Dual-layer
cloud classification

Dual-layer
high-cloud Tau

Dual-layer
low-cloud Tau